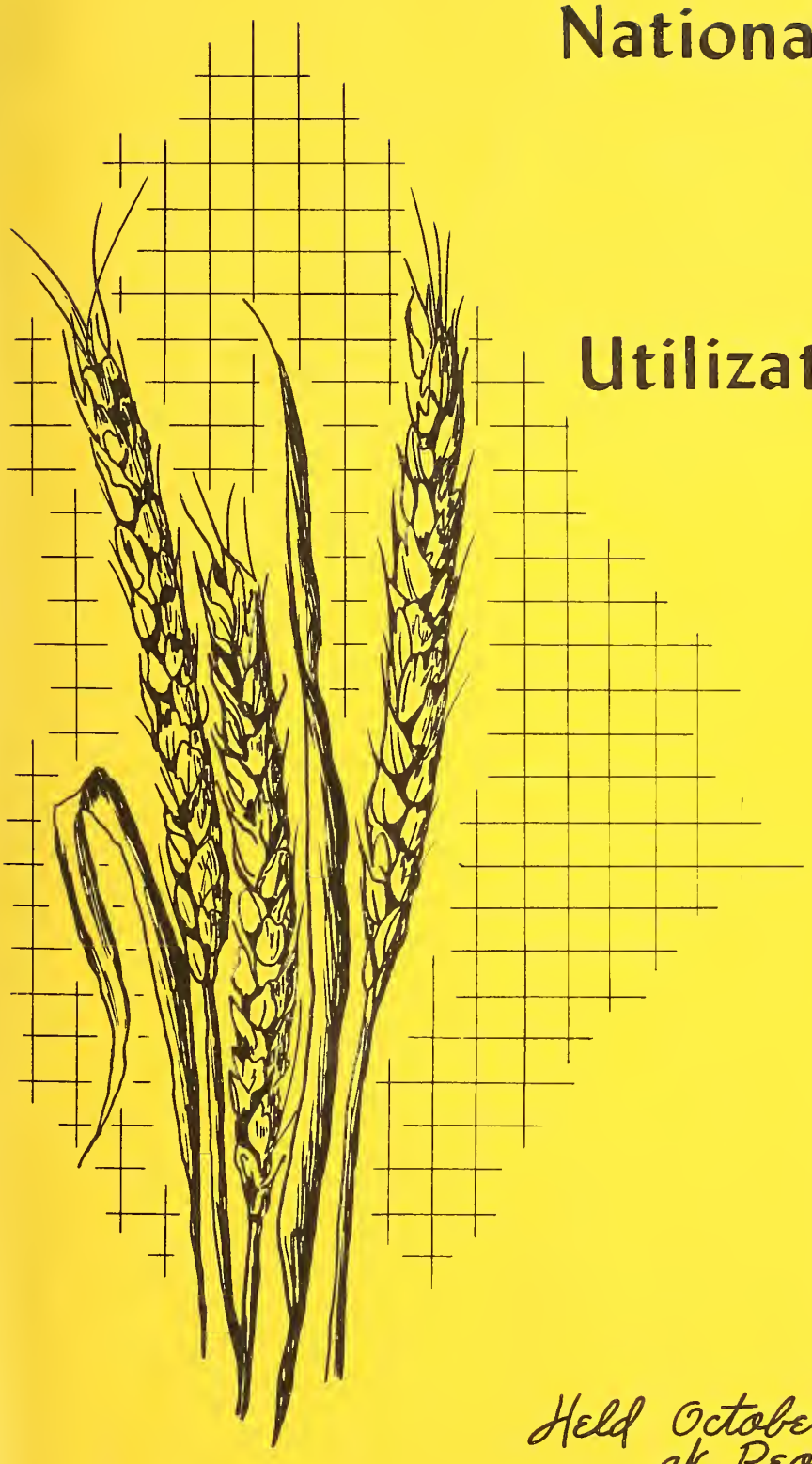
March 1964

Second National Conference on Wheat Utilization Research



Held October 28-29-30, 1963
at Peoria, Illinois

Foreword

REPORT OF
SECOND NATIONAL CONFERENCE ON WHEAT UTILIZATION RESEARCH

The Second National Conference on Wheat Utilization Research was held in Peoria, Illinois, on October 28-30, 1963. The objectives of this meeting were essentially those advanced at the First National Conference held in Lincoln, Nebraska, on October 29-31, 1962. These objectives are to provide a common meeting ground where the various groups interested in wheat utilization can present information that will promote the wider use of wheat products. At these meetings an exchange of ideas, problems, and answers by producers, processors, and consumers of wheat should lead to a better understanding of interdependent relationships of research in production, utilization, and marketing of wheat.

The following organizations sponsored the Conference:

National Association of Wheat Growers
Great Plains Wheat, Inc.
Western Wheat Associates, Inc.
Western Utilization Research and Development Division
Northern Utilization Research and Development Division
Other participating agencies of USDA

This report, which was prepared at the Northern Utilization Research and Development Division, Peoria, Illinois, contains the complete text or summaries of talks given at the Second National Conference. Copies are available on request.

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REPORT OF CONFERENCE ON WHEAT UTILIZATION RESEARCH

WELCOME

F. R. Senti, Director,
Northern Utilization Research and Development Division,
ARS, USDA, Peoria, Illinois

It is my pleasure, at this first session of the Second Annual National Conference on Wheat Utilization Research, to welcome you as guests and participants in this event. I also want to welcome you to Peoria and to the Northern Regional Laboratory. We had hoped to hold this Conference at the Northern Laboratory but the attendance indicated by the response to the first mailing on the Conference was greater than our facilities could accomodate. For this reason the Conference is being held at the Hotel Pere Marquette. However, we invite you to visit the Northern Laboratory and we have arranged a tour on Wednesday afternoon to provide an opportunity to do this.

The First Annual Conference, held last October at the Nebraska Center for Continuing Education, in Lincoln, Nebraska, was considered an outstanding success by those attending. Consequently, it was decided that, because of the importance of wheat in our economy, and the many aspects of wheat utilization that research is revealing, these conferences should be held annually. At that time, Peoria was selected for the 1963 meeting.

The program for the present conference was planned under the able leadership of Howard Morton, Chairman, Program Committee for the National Wheat Utilization Research Conference. As most of you know, Mr. Morton is also Vice-Chairman, Utilization Advisory Committee, Great Plains Wheat, Inc.

In planning the program, many individuals contributed suggestions for topics to be presented. These were considered at a program committee meeting held last April in Minneapolis, Minnesota. Members of this committee are: Howard Morton; James W. Pence of the Western Regional Research Laboratory; H. Wayne Bitting, Process and Product Evaluation Staff, ARS; Kenneth A. Gilles, North Dakota State University; William B. Bradley, American Institute of Baking; Paul J. Mattern, Nebraska Agricultural Experiment Station; Mark Barmore, Western Wheat Quality Laboratory, Del Pratt, Pillsbury Company; Robert Sheffels, Western Wheat Associates; M. J. Copley, Western Utilization Research and Development Division; and myself. It will be impossible to offer specific recognition by name to the many others who made suggestions for contributions to the program. On behalf of the committee,

I should like to express our appreciation to them. As a result of these joint efforts, I believe that an interesting and informative program has been planned. Before beginning this morning's session, I should like to outline the objectives of the five sessions to follow.

This morning is a general session to present to you an overall view of the USDA research program and the place of wheat in that program together with several aspects of the efforts, by industry and by government, to expand utilization of wheat at home and abroad.

The afternoon meeting is on industrial uses of wheat and milling research. I believe that there is sufficient diversity in the topics to stimulate the interest of most of the group.

Tomorrow morning, you will hear talks on two phases of wheat breeding, on milling of soft wheat, control of insect infestation, and freezing of bread.

Tuesday afternoon will be devoted to food uses of wheat, and the final session on Wednesday morning, to the chemistry of wheat.

The Conference ends formally at noon on Wednesday. As you will see from the program, we have arranged for a tour of the Northern Division for Wednesday afternoon. The tour will emphasize the programs which we will discuss at the Conference. However, we will be pleased to cover other phases of our work which may be of interest to any one of you.

With this preamble, I should like to introduce Glen L. Bayne, President, National Association of Wheat Growers, who will chair our first session.

AGRICULTURAL RESEARCH - ITS SUPPORT, PROGRAMMING AND OBJECTIVES

George W. Irving, Jr., Deputy Administrator and
Sam R. Hoover, Assistant to Administrator[1]
Agricultural Research Service, U.S. Department of Agriculture

The objective of agricultural research is to discover, develop, and apply new knowledge for the improvement of agriculture. Scientists in the U.S. Department of Agriculture, State agricultural experiment stations, and industry share responsibility for achieving this objective and work in partnership to develop scientifically tested knowledge to assist all who are a part of this agricultural industry--producers, processors, and marketers--to do a more effective job. In all of this, primary consideration is given the welfare of the consumer--the "customer" of the agricultural industry--as well as the efficient use and further development of our natural agricultural resources.

It is hardly necessary to remind a group of this kind that this partnership has been successful. Science and technology have transformed American agriculture in the space of a lifetime. As a direct result:

Farmers in the United States are producing food and fiber on the world's most efficient farms.

New machinery and equipment take much of the drudgery out of farming.

One worker can produce twice as much as he could 20 years ago.

Good breeding, feeding, and management practices have helped build a livestock industry unmatched anywhere else in the world.

The farmer has available a wide variety of crops, especially bred to improve their quality, hardiness, and resistance to insects and pests.

More effective conservation techniques are helping save our soil, water, and trees.

Higher incomes from more efficient farms mean better homes, better schools, better community life.

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[1] Presented by Dr. Hoover at the Second National Conference on Wheat Utilization Research, Peoria, Illinois, October 28, 1963.

The nation, as a whole, benefits from more efficient marketing and distribution, from safe food supplies, from a greater variety, year round, of high-quality farm products, and from better diets for all our people.

Finally, agriculture's efficiency has released labor from our farms to produce other goods and services, thus speeding the development and growth of our industrial economy.

We can say quite proudly, therefore, that agricultural research is at work on the farm, in the community, and for the nation.

Support of Agricultural Research

To orient us with respect to the magnitude of agricultural research, we will start with a few statistics on the total national effort in research and development.

In fiscal 1963, total Federal expenditures for research and development were $12-1/2 billion. It is estimated that expenditures by industry and other nonfederal organizations amounted to an additional $5 billion, making a total of over $17 billion.

In 1961, the latest year for which complete data are available, total national expenditures for research and development amounted to about $14 billion. Of these funds, the Federal government provided about 64 percent, State governments and nonprofit institutions about 3 percent, and industry about 33 percent.

About one-half of the support for agricultural research is provided by the Federal and State governments and one-half by industry. Federal appropriations for agricultural research during the fiscal year 1963 totaled approximately $169 million, of which $131 million was available for direct research by U.S. Department of Agriculture agencies and $38 million for payments to State agricultural experiment stations. The States provided about $142 million. These Federal and State appropriations amount to $311 million in public funds spent on agricultural research in fiscal 1963. The expenditures of industry in this area are estimated at $380 million.

In addition to the research done by industry and private institutions, these organizations contribute to the research carried out by State stations and $850 thousand to the U.S. Department of Agriculture. The value of nonmonetary contributions from private sources to State and Federal programs is larger than the monetary support. Many contributions are in kind--that is, products, materials, and equipment given or loaned for use in the conduct of investigations.

There has been a gradual increase in Federal funds for agricultural research since World War II. Expenditures increased from $29 million in

1940 to $169 million in 1963. Although there has been almost a sixfold increase in funds, because of rising costs of research and differences in purchasing power of the dollar, these funds actually support only a little more than twice as much research as we had in 1940.

We should note another significant and interesting point. While Federal support for research in agriculture has grown since World War II, it has not grown nearly so fast as Federal support for research in other areas. In 1940, agriculture received about 40 percent of all Federal funds for research. By 1950, although Federal research funds had grown considerably, agriculture's share had dropped to 5 percent of the total and now agriculture receives 1.2 percent of the Federal funds for research.

Funds from all sources for agricultural research and development, more than half of which comes from industry, represent about 3 percent of the nation's total research and development expenditure.

Let us look now at the manpower devoted to agricultural research and development. Last year a total of about 26,000 scientists were working in 11 broad areas representing the spectrum of research in food, agriculture, and forestry. Of this total, about 5,000 were employed in the U.S. Department of Agriculture, 5,200 at the State agricultural experiment stations, and 15,500 in industry.

Both industry and the public agencies had a large portion of their programs in the areas of Protection of Crops and Livestock, Producing Quality Products Efficiently, and Economics of Production and Marketing. Compared with the public agencies, industry placed more emphasis on Industrial Uses for Farm Products, New and Improved Food Products and Feeds, Maintaining Quality and Reducing Costs in Marketing, and Rural Family Living. In the area of Rural Family Living, industry concentrated its efforts on research basic to the development of household equipment, while the State and U.S. Department of Agriculture programs emphasized research on the requirements for and care of clothing, housing, and household equipment, surveys of rural levels of living, and home management practices. It is also apparent that the research on soils, water, and conservation represented a very small part of industry's program. Industry cannot be expected to devote any considerable effort to the search for new knowledge in these fields.

Character of the Agricultural Research Program

By whom is the Department's agricultural research conducted? What is the distribution of effort among basic and applied research and development studies?

Most of the Department's research is conducted intramurally--in Department facilities by the staff of the Department. A substantial part, however, is done extramurally--by contractors and grantees. All the major Federal research and development agencies rely to a varying degree upon outside organizations for performance of research and development. Among the six

largest research and development agencies, the percentage of their fiscal 1962 funds obligated for extramural performance ranged from 18 for Department of Commerce to 81 for National Aeronautics and Space Administration. About 29 percent of the Department of Agriculture's research and development obligations were for extramural research. The extramural performers include profit and nonprofit organizations and educational institutions--both domestic and foreign.

One or two general statistics will help orient us with respect to the relative emphasis in agriculture on basic or applied research and development.

Of the 1963 Federal budget for all research and development, development accounted for 65 percent, applied research 23 percent, and basic research 12 percent. Comparable figures for the distribution of all of industry's research and development outlays are 76 percent for development, 20 percent for applied research, and 4 percent for basic research.

The Department of Agriculture's 1963 research and development funds were allocated as follows: 4 percent for development, 61 percent for applied research, and 35 percent for basic research. In the Department of Agriculture's Agricultural Research Service we are continuing strong emphasis on basic investigations, and are moving toward allocating as much as 50 percent of our research funds for this purpose.

In the State agricultural experiment stations more than 35 percent of their effort is for basic research and increasing emphasis in this direction each year has raised this percentage above 50 percent at some locations.

Programming of Agricultural Research

The diversity of American agriculture, the growing interdependence of all science, and the number of organizations engaged in research make the planning and coordination of agricultural research a formidable undertaking.

Administrators must insure that the important problems receive adequate attention; that shifts in economic and other conditions are properly reflected in the research program; that unnecessary duplication of work is avoided; and that the benefits expected from particular lines of work justify the effort devoted to it.

Choosing the best ideas for incorporation in any research program is, of course, important. It is equally important to stimulate the generation of good ideas from which a choice can be made. Accordingly, the Department encourages both the inflow of good ideas from outside and the generation and interchange of ideas at all points within the system. Several devices are used.

Advisory Committees.--The Department makes use of policy and commodity advisory bodies to solicit comments on its research program from those best acquainted with the problem under investigation. Members of those committees

represent the major segments of United States agriculture and the consuming public. These committees meet annually--or more frequently--to review current research and recommend adjustments, including termination of existing projects, expansion of current work, and initiation of new work.

The Committee on Agricultural Science.--A 15-member advisory group of outstanding professional personnel--consisting of 10 chemical and biological scientists and 5 economists--reviews, evaluates, and makes recommendations concerning U.S. Department of Agriculture research in the basic sciences. This committee was appointed by the Secretary of Agriculture in April 1962, upon recommendations made by the President's Science Advisory Committee. These eminent scientists represent such disciplines as genetics, microbiology, ecology, nutrition, physiology, entomology, engineering, biochemistry, physics, rural sociology, marketing, and economics.

The U.S. Department of Agriculture National Agricultural Research Advisory Committee.--This committee composed of 11 members with broad national interests in all phases of agriculture, evaluates the Department's entire research program and offers suggestions for modifications, additions, and deletions. This committee meeting quarterly, is concerned chiefly with research policy.

The Research and Marketing Act Advisory Committees.--Eleven in number, covering commodity and functional fields, meet at least once each year to render specific advice on problems that should receive greatest research attention. Some meetings are scheduled at research installations to permit firsthand knowledge of the research being conducted there.

State Agricultural Experiment Station Collaboration.--The Directors and designated technical collaborators of the State Agricultural Experiment Stations, in the respective four national regions, assist in planning research activities of mutual interest to the Federal and State groups. Much of this planning leads to cooperative research efforts, through memoranda of understanding, with considerable savings in time and money.

Regional research has increased consistently since the establishment of the Regional Research Fund in 1946. Cooperative projects are recommended by a committee of nine elected by and representing the State station directors. The projects are planned by technical committees composed of Department of Agriculture and State representatives.

Agricultural Trade Associations.--Recognized national and regional groups of growers, processors, handlers, carriers, and distributors are constant sources of advice on broad research needs as well as on problems of immediate urgency.

Consultants.--Some 40 experts, who are recognized authorities in particular scientific fields, are retained on a "when actually employed" basis. These people render readymade technical and economic advice to assist in program planning and evaluation.

Consumer Groups.--Representative consumer groups of national and regional scope provide sound guidelines for research planning through their evaluations of product performance and through suggestions as to product needs.

The Project System.--Scientists at all levels of the Agricultural Research Service play an important part in the initiation and planning of research. They recognize problem areas where new facts are needed, and propose promising approaches. The Administrator determines in each case whether a proposed project will contribute to the solution of the most urgent research problems and fits into a well-balanced total program of research. The Administrator is assisted in this work by a Central Project Office and an Agricultural Research Council.

The Central Project Office is the control center for the review and approval of research proposals. It maintains records on about 3,000 Department line projects. Each proposed project is examined in this office in relation to the Department's existing program and referred for comment to all agencies of the Department doing related work.

Agricultural Research Council.--The Department's Agricultural Research Council consists of the Deputy Administrators for Research in the Agricultural Research Service, the Agricultural Marketing Service, the Economic Research Service, the Cooperative State Experiment Stations Service, the Soil Conservation Service; the Assistant Chief for Research of the Forest Service, and the Administrator of the Statistical Reporting Service and the Farmer Cooperative Service. It provides a forum for discussion of research problems of Department-wide concern. The Deputy Administrator for Research Planning and Coordination, Agricultural Research Service, is its chairman.

Cooperation with Industry.--For the most part cooperation with industry is informal. However, industrial research grants, endowments, and fellowships play an important part in the Department's cooperative research. Facilities, materials, and the services made available by private concerns aid many phases of both Federal and State research. Much of the formal cooperation with industry, including that described by written agreements, is handled through various industrial associations. The cooperation and assistance of industrial and educational groups have contributed importantly to the success of agricultural research. Cooperative relationships between the agricultural industry and the public agricultural research institutions have flourished and accelerated over the years. These cooperative relationships give the Department's research more vitality than it would have if we attempted to operate in isolation. Some of our problems would be virtually insoluble unless we were able to approach their solution together.

A concluding word on research programming is in order. Successful research depends primarily on the ability of individual scientists. To generate the new ideas on which scientific progress depends, they must be talented and well-trained individuals and they must have the freedom to use their imaginations. The privilege of participating in fundamental and pioneering research is important to many scientists. About 20 pioneering research laboratories have been established in the Department to encourage such research. Not only do these laboratories create new knowledge of great value, they also help create a better research environment in the Department.

Current Grain Research Programming

Two specific research programs are of particular interest to those participating in this meeting: research on grain in the United States and research on wheat in the Department.

Some 2,000 researchers are employed in the grains research program of the States, the Department, and industry. Of this total, nearly two-thirds work in the laboratories of industry where the emphasis is primarily on utilization research. Farm research, which receives greatest emphasis in the State agricultural experiment stations, includes investigations on plant introduction, breeding, and genetics, variety evaluation, culture, diseases, nematodes, weed control, insects, and crop handling and harvesting equipment and structures. Grain utilization research which deals with new and improved feed, food, and industrial products and processes is given equal emphasis in the Department with farm research.

The Wheat Research Program of the Department.--The Department devotes about one-half of its research on wheat to utilization and half to production, marketing, and economics.

Production research is conducted by the Crops, Entomology, Agricultural Engineering, and the Soil and Water Conservation Research Divisions of the Agricultural Research Service. This program includes the breeding of superior wheat varieties, research on pest control, and improved cultural practices, as well as the design of planting, fertilizing, and other equipment and facilities used by the producer.

Wheat marketing research is done by the Agricultural Marketing Service in the Market Quality Research Division and the Transportation and Facilities Research Division. Means are sought for eliminating or minimizing damage or deterioration in wheat quality in marketing channels through normal metabolic changes, by the action of micro-organisms, and by the attacks of various insects. Means are also sought for providing objective measures of wheat quality. Investigations are under way on grain aeration and drying, the design of storage structures, and on the development of improved methods and equipment for handling grain in terminal elevators.

Economic research on wheat is conducted by three Department agencies--Economic Research Service, Farmer Cooperative Service, and Statistical Reporting Service. This work includes determinations of the market potential for wheat products, costs and efficiency analyses of grain storage and handling, and the improvement of crop estimating procedures.

Nutrition and consumer use research on wheat is an important part of the studies of the Human Nutrition and the Consumer and Food Economics Divisions of the Agricultural Research Service, both of which are centered in the Washington-Beltsville area. In these divisions, wheat gets appropriate attention in research on the biological evaluation of food, food composition and quality, diet appraisal, and food economics.

Utilization research on wheat is conducted at the Agricultural Research Service's Northern Utilization Research and Development Division here in Peoria and at its sister laboratory, the Western Utilization Research and Development Division at Albany, California. Both laboratories seek to expand uses of wheat by improving traditional wheat products and by developing new ones. Emphasis at Albany is on food uses; here at Peoria on industrial uses.

I have concluded with this brief mention of the places in the Department where research on wheat is being conducted, again for purposes of orientation. Most, if not all, of those areas will be discussed in detail by those who are to follow me in these sessions.

My principal purpose has been to leave with you an impression of the magnitude of agricultural research in the United States today, the sources of funds supporting it, the care that is taken to assure effective research programs, and the diversity and intensity of the Department's research on wheat and other cereals.

UTILIZATION IMPLICATIONS OF THE WHEAT SUPPORT PROGRAM

J. A. Schnittker, Agricultural Economist,
Staff Economists Group, Agricultural Economics, USDA,
Washington, D.C.

Summary

I want to review first of all my understanding of the present position of wheat as an industrial raw material; secondly, the changes introduced in

wheat legislation and in future wheat programs by the Agricultural Act of 1962 and by the recent wheat referendum, and third to discuss then the major utilization implications which flow from these changes.

Given the present state of technical knowledge on processing of wheat for industrial purposes, there appears to be little immediate opportunity for measureable increases in industrial wheat utilization. For presently known products such as alcohol and starch, I understand that wheat would have to be available at prices one-half to one-third of present levels before large scale industrial use would be feasible. It appears on the surface then, that there is a large gap to close between technical and economic feasibility.

Work currently underway to utilize wheat in the manufacture of pesticides, bactericides, and paper, for example, may ultimately raise the intrinsic value of wheat as an industrial raw material. However, development of these processes is uncertain. We are here at Peoria today to discuss just the promising processes and to weigh their prospects. I have come to learn--not to pronounce.

The Agricultural Act of 1962 improved the prospects for utilization of wheat for industrial purposes through its effect on wheat pricing. For the first time in many years all wheat marketed in the U.S. would be valued at price levels geared to its merit as a feed, and to its value in world markets.

The procedure established by the Act to carry out this revised market price structure and at the same time to maintain incomes of wheat farmers at recent levels is known as the "Marketing Certificate Program." A part of the income of wheat farmers would be derived from a market price of wheat based on its value in feed and world markets, and a part through an administrative procedure which transfers to farmers the higher price paid for wheat by domestic millers and to some extent, transfers export subsidy payments to farmers.

Under procedures developed prior to the wheat referendum, wheat would be priced in the market at levels related to feed and world values. Millers would generally purchase the marketing certificate after wheat was milled--not at the time wheat was purchased. But anyone who wanted to make use of wheat for feed or for industrial purposes not related to food uses, would have been able to acquire wheat at a price approximately one-third lower than for many years.

The important point is then, that wheat as a raw material for nonfood purposes is substantially cheaper under the new wheat program than under the old. In fact, under existing law, wheat for feed and for industrial uses will be priced at approximately the same level whether the wheat farmers approve the program in the referendum or whether they disapprove the program.

It is not only wheat but also flour which is a potential raw material for nonfood products. Without going into the details of how flour for nonfood uses could be distinguished from flour to be used as food, I would only

say that there is authority in the law and it is the intent of the law that products not primarily food be exempt from the cost of the marketing certificates. So the fact that some industrial process may use flour instead of wheat does not alter the fact that the raw material cost is very substantially reduced by the new wheat program.

Even the decline of one-third in prospective wheat values for certain users is not nearly adequate to make wheat an attractive raw material for the processes or the products now available. Thus, it would appear that the change in the law will only have a marginal impact on the total value of wheat used for industrial purposes. But the price disadvantage of wheat as a raw material is certainly reduced, and the scientific and technological task in making wheat a feasible raw material for processes not now in use, is made easier.

The one outlet remaining then for increased utilization of wheat is for livestock feed. There was a time when wheat was used very widely for livestock feeding. It is the preferred feed grain in the Pacific Northwest and will undoubtedly be used very heavily in that area if its price were again competitive with coarse grain prices.

The Department of Agriculture has estimated that either under the program offered in the referendum early this year or the program in effect as a result of the referendum, feed use of wheat could be three or four times as great as it has been in recent years--perhaps as high as 200 million bushels per year. This availability of wheat as feed may have a substantial impact upon the location of feeding enterprises and may tend to encourage the location of feeding enterprises near sources of wheat even though they would have been located elsewhere if wheat had continued to be noncompetitive as a feed grain.

FOREIGN TRADE IN WHEAT--CURRENT EVALUATION AND PROSPECT

R. E. Vickery, Director,
Grain and Feed Division, Commodity Programs,
Foreign Agricultural Service, USDA, Washington, D.C.

The subject which I was asked to discuss--Foreign Trade in Wheat, Current Evaluation and Prospect--would not appear at first glance to have much in common with wheat utilization research. However, a glimpse at only

a few of the titles of talks to be given by the scientists here during the next few days should be enough to convince any layman--or economist--that there is indeed a large area of mutual interest between scientist and merchant.

I am not a scientist and for that reason it never ceases to amaze me that the complexities of civilized man's basic food, the cereal grains, still hold so many mysteries. Perhaps it is because grains, like ourselves, are living, dynamic systems containing an infinite number of variables which simply won't hold still so they can be systematically analyzed.

In your studies, whether in public or private institutions, you will be wise to keep in mind that wheat, which is basically a human food, is now being grown so efficiently and widely that its production exceeds the needs of the free world market. This is despite the fact that total world trade in wheat has increased about 50 percent in the past 10 years, outstripping population growth. Total world trade reached 1-1/2 billion bushels a year ago. Literally millions of people are getting a substantial portion of their daily nutritive requirements from wheat today who were unacquainted with wheat a scant 10 or 20 years ago. So, while markets and population have increased, man's ability to increase production has expanded even more. New uses for wheat, which would keep its price advantage over the other cereal grains, are certainly worth researching.

One such new use that is expanding rapidly and finding widespread acceptance in developing countries is bulgur. This scientific application of 20th century engineering know-how to the ancient bulgur process of the Near East has opened an ever widening avenue for wheat into millions of stomachs. There is no way of predicting how many more ideas of similar merit lie latent in the minds of men and women like you. It is a challenge that I offer anew to our fine research institutions, both public and private.

Foreign trade in wheat is as complex, almost, as the chromosomes and genes which determine its inheritance. And, like inherited characteristics, some factors are dominant and others are considered to be recessive or less important. For example during the past marketing year our total exports of wheat and flour were approximately 638 million bushels, a drop of 80 million bushels from the record high of the previous year. This is a reduction of 11.2 percent.

Let's take a little closer look at this export figure of 638 million bushels--not with a microscope but with a magnifying glass big enough for our present purpose.

The first dominant fact that comes to light is the magnitude of the figure itself. It is bigger than the total disappearance of wheat in the United States that same year for food, feed, seed, and industrial use. This is the third consecutive year in which exports have dominated the domestic market as the most important outlet for our wheat producers.

Having discovered--or rediscovered--this fact let's look further at our export trade in wheat. An item comes into view called Public Law 480. Its various titles include the disaster, work projects paid for in wheat, aid, donations, long-term credit, and barter sales as well as the biggest item of sales for foreign currency made under Title I. The outstanding feature of our exports under PL 480 is the volume. During 1962-63 we exported 482 million bushels under this heading--nearly as much as was milled into flour for domestic consumption in the same period. Compared with the same category of exports a year earlier, they are down about 2 percent.

The second type of export sales is simply called "Sales for Dollars." These are sales made in competition with other exporting countries. You can safely surmise from what I have already said about the worldwide production of wheat that competition for sales in the dollar markets is pretty sharp. By this time those of you with mental calculating machines have already figured out that sales for dollars in 1962-63 were about 155 million bushels. By happenstance this is about average of our dollar sales over the past 10 years. The preceding year was much better with sales for dollars exceeding 227 million bushels. The 1962-63 dollar business was down 32 percent. Remember that PL 480 exports decreased only 2 percent.

Our biggest drop in dollar sales was in Europe--U. K. and the Common Market countries. If I had to decide which of the many factors causing markets to rise and fall were dominant and which ones recessive I'm not sure anyone else in Government or the trade would agree with me completely. We all see things through an individual pair of eyes--our own.

Certainly one of the primary reasons for the fluctuation in wheat import requirements of most countries is the size and quality of their indigenous crops. The 1962 harvest was better than average in most importing countries, including the U. K. and Western Europe. Exports of wheat and flour for dollars to the free world was, as a result, down substantially. In our own case this reduction was 72 million bushels compared to a drop in Canadian exports for dollars to the free world of 33 million bushels. Offhand this indicates a stronger demand for Canadian dollar sales exceeding U.S. dollar sales by 50 percent and being less subject to fluctuation.

We have the benefit of almost countless evaluations by U.S. grain trade representatives, including producers, of the competitive position of U.S. wheat in various markets.

I will summarize the concensus of these evaluations.

1. Most U.S. hard wheat is considered to be of "filler" quality when compared to Canadian Manitoba. Requirements for "filler" wheat generally vary inversely with the production in importing countries.

2. The market appearance and value of U.S. wheat would be measurably improved if the unmillable material were reduced to a competitive, or near competitive position. The proposed changes in the Grain Standards would be a big step toward this goal.

3. Somewhat unreliable baking strength in U.S. wheat from one shipment to another. Protein content of U.S. wheat is not a reliable measure of baking strength.

4. Hard Red Spring wheat, while in abundant supply, is out of position and therefore noncompetitive in major spring wheat markets, like the Philippines, Japan, Latin America, and Africa.

There are other reasons also, of course, why importing countries may direct their wheat purchases in one direction or another including:

1. Trade balances.
2. Credit arrangements.
3. Barter deals.
4. Presence or lack of trade barriers including political barriers and tariffs, quotas, etc.

Sometimes these reasons outweigh all considerations involving type of wheat, quality, or price. But in the majority of cases importing countries buying for dollars exercise their economic prerogatives of making their purchases in the world market place, letting competition among sellers determine price (with the IWA) and quality.

I firmly believe the United States, with its wide variety in wheat types and qualities, like a vast supermarket, could assume the lead in wheat sales for dollars if we would clean up our wheat by tightening the grades, put a measure of bread baking strength on our wheat as it moves overseas, and refrain from sending storage-deteriorated wheat to high quality dollar markets.

It is also obvious that we must have the desired qualities of wheat in adequate supply at or available to all major ports at competitive prices if we are to maintain or expand our dollar trade in wheat.

Like yesteryear's automobiles or airplanes, the qualities of wheat which satisfied the market demand of 10 or 20 years ago no longer measures up to today's job. Stronger wheats are needed to blend with the increased production of most wheat deficit countries and the increasing use of high speed baking machinery. In some areas, like Western Europe, the need for imported filler wheat in substantial amounts exists only in years of below normal production. (Note: 1963-64 may be one of those years with a poor crop in Europe, Japan, and Russia.) In Japan, where per capita consumption of wheat products has nearly tripled in the last quarter century, over two-thirds of the import requirements are for a strong bread wheat, which was imported in only minor quantities 10 years ago.

Almost without exception, countries which have shifted from a flour importing to a wheat importing status require very strong bread wheat for the bulk of their imports.

No exporting country can expect to gain or hold these markets with a product or marketing methods which fail to satisfy the end user. It is axiomatic, of course, that before we can sell something we must produce it. I am in full agreement with others who say we have little surplus of good quality bread wheat. There certainly is no danger, in my opinion, of over production of strong gluten-high sedimentation hard wheat, as some have suggested.

For a change of pace, I should like to give you a little more information on exports of wheat and wheat flour under PL 480. The six biggest in volume are: India, Egypt, Turkey, Brazil, Yugoslavia, and Pakistan (in that order for 1961-62). Together they received two-thirds of all the wheat and wheat flour exported under PL 480. Of these, Egypt is the largest market for flour, a large portion of aid to that country being in the form of wheat flour. We are hopeful that eventually all will be commercial dollar customers. Except for Turkey and Yugoslavia, the big PL 480 markets represent mass feeding of wheat to populations that previously had little or no experience with it. Certainly a taste of wheat products is being developed which will have a lasting effect on total world demand. The assistance given by us to less fortunate people under PL 480 is by all odds the greatest humanitarian effort in the history of mankind. As long as the need for these programs exists and as long as we, through the Congress, approve the appropriations to finance them, we will probably have our wheat exports dominated by PL 480 programs. These programs accounted for 75 percent of our total wheat and flour exports in 1962-63. Most of our promotional efforts in FAS, working with cooperating organizations, is--and must be--to increase dollar sales.

I have thus far given you but a few of the highlights of our problems and opportunities; in a market as complex as the world wheat market it is never all good or all bad. While we suffer losses in one sector we may profit by gains elsewhere. This is what has happened this past year and what appears to be continuing this year. Our sales to Europe are at a low ebb, for reasons already enumerated. At the same time we are experiencing a significant increase in wheat exports to Japan. During the 1962-63 marketing year our sales to this dollar market increased 15 percent and exceeded 35 million bushels. Japan is, and has been for several years, a bigger dollar market for U.S. wheat than all six Common Market countries combined.

This phenomenon didn't just happen. It represents an excellent example of cooperation between the U.S. government and wheat industry interests in market promotional activities of the broadest and most intensive sort. It represents also a desire of the Japanese government to shift a significant portion of her wheat imports to the U.S. for balance of payments reasons.

Very serious domestic barriers to the sale of quality hard wheat to Japan had to be overcome, the most difficult being a reduction of inland freight rates. Prior to the lowering of west bound rates from the western area of the Great Plains, wheat grown in America's breadbasket could move only to eastward or southward markets. The present 70 cents/cwt. rate was vigorously opposed by some but the case for it was strong and ably presented by wheat producer interests and the Department of Agriculture.

A similar reduction in rail rates is sorely needed in the Hard Red Spring wheat area to enable this class of wheat to compete with Canadian Manitoba exported from Vancouver, B.C.

I have rambled here from pillar to post, trying to cover only a few of the multitude of facets that combine to form the complete picture of international trade in wheat. I have emphasized areas which seem to us to be of paramount importance to the U.S. interest such as:

1. The need to raise the quality and uniformity of U.S. exports to competitive levels.

2. The importance of gearing production to meet export quality requirements.

3. The need to reduce internal transportation rates so that wheat of all classes can be available for export from all coasts at competitive prices.

BULGUR EXPORT TRADE DEVELOPMENTS

J. L. Locke, President
Fisher Flouring Mills Company, Seattle, Washington

This is the first opportunity that I have had to attend one of your meetings, and I must confess to a feeling of being beyond my depth. Although I have known from technical and scientific men in our organization the splendid work that is being done by the Regional Research Laboratories of the USDA, a man who started out to be an attorney, and ended up being a flour miller, cannot be expected to contribute very much of a technical nature to you, and therefore I shall not try to do so. Later on in the program, others will give you the scientific data that have been developed.

You have asked me to talk about bulgur-wheat. It seems to me particularly significant that I, who always want to consider myself a salesman, should be asked to address you about merchandising bulgur. It indicates the change in your activities, and the breadth of your interests. Years ago a practical commercial application of research--much of which was basic--was, if not overlooked, given small consideration in the work that was being undertaken. That is not true today. Bulgur typifies the accomplishments that can be made when Government and industry combine their efforts--research, engineering, and promotion--with a common objective--to introduce a new food to the world. Bulgur is unique in the many people and organizations that have taken part in its development. High on this list is the Western Regional Research Laboratory at Albany, California.

It was in 1952 when Gordon Boals, Vice President and Director of Exports for the Millers' National Federation, first brought bulgur to the attention of the milling industry. He had found areas where there were no facilities for, and no knowledge of bread....and small understanding of, or interest in it. In some of these areas he was introduced to bulgur wheat and, lookingfar into the future, felt that bulgur would be an ideal and compatible companion to the sale of flour. After a number of meetings where Gordon extolled the advantages of bulgur-wheat, he generated a few sparks of interest within the milling industry but very little heat or enthusiasm.

At about that time, Fisher Flouring Mills Company bought a feed and fertilizer plant directly alongside its property in Seattle. This plant had an excess of boiler capacity, a three-story manufacturing building, and ample grain and dock storage. It seemed to be well suited for the manufacture of bulgur when used in conjunction with the facilities of the Fisher plant, subject to the big question--could we find some way to produce it? After many frustrating months we had made sufficient progress to build a small pilot plant in our laboratory to produce bulgur by a straight-line, continuous method. We found it to be palatable, nutritious, and quick cooking, like rice.

During the early 1950's, the need for food throughout the world was acute. This was particularly true in rice-eating areas of the Orient. There was great concern that the rice bowl of Southeast Asia would be invaded and rice would not be available to importing countries. We knew that neither wheat, as such, nor flour, would serve to prevent famine in some of these areas; they had neither the knowledge nor the facilities for its use. Bulgur seemed the only answer to the need.

With our recently acquired knowledge, we took the product to Washington. The State Department was interested, for in bulgur they found a method of feeding our friends if rice were not available. Commerce, also, wanted to rebuild the commercial exports, and Agriculture could see a new use for wheat that would alleviate the recurring problems of surplus. In many discussions, we explored the advisability of the United States Government's furnishing the

special equipment required to manufacture bulgur, while we would furnish the buildings, the grain storage warehouses, cleaning, packaging, loading, etc. ....about 80 percent of the required investment for Fisher's, and 20 percent for Government. We would man and operate the plant. This was at a time when Government was building facilities to be operated by industry in cases where the products were urgently needed.

After many months of study by first one department and then another, in which--after many delays--it was decided the program had merit, the Commodity Credit Corporation was instructed to negotiate a contract to be submitted for their approval. The problem then became one of draftmanship, with the resemblance between the final draft and the original discussions, purely coincidental. Without going into details of the many months of negotiation, some of the serious and some of the ludicrous things we ran into, a contract ultimately was signed which provided that 500,000 bushels of wheat would be allocated to the manufacture of bulgur, 250,000 bushels of this to Fisher Flouring Mills Company. We were to manufacture, pack, sell, and deliver the bulgur to selected areas approved by the U.S. Department of Agriculture. It was up to us to sell the product for enough to pay for the cost of production, transportation, selling, amortization, administration, etc. In the event a final accounting proved that Fisher had made a profit on the sale of the bulgur, that profit was to be surrendered to the USDA, in full or partial payment for the wheat supplied. In the event we were unable to sell for a sufficient amount to pay for these charges, Fisher was to bear the loss. In passing--we came pretty close--the final accounting showed Fisher had lost approximately $10,000. By this time--1954--the acute world food shortage no longer existed, and we had to sell bulgur without benefit of Public Law 480, enjoyed by wheat and flour.

However, we did prove that people will eat bulgur. We proved that they will buy it, and we sold it in many areas from Korea to Lebanon. The sales were not easy. We learned that low prices--one-half the cost of rice--would not sell a new food. We heard in many languages, with and without profanity, with or without eating the product, "It is not rice," but slowly and gradually bulgur made friends.

As soon as shipments of bulgur were authorized for the Far East--an area in which we have sold flour for over 50 years, our export manager left for the Orient on the first of several bulgur promotion trips. Able demonstrators and home economists were employed at our expense--native people, by and large--to teach our own Commercial and Agricultural Attaches, and the representatives of the various voluntary relief agencies, what bulgur is, and how it could be used. They developed recipes, particularly suited to each area involved. They served many, many meals, not only to our embassies and the voluntary relief people, but to food ministers and those responsible for the distribution of foods in the recipient countries. With their cooperation, our demonstrators and home economists went into the field. They went to the various places where there was a concentration of people--relief feedings, schools, mass feeding depots, service groups..Army, Navy, etc. They then

went into the country and demonstrated wherever a few people could be brought together, explaining this new food, what it is, how it could be used, how it could be prepared. It was not enough to say, "Cook it just like rice," for we were not selling a substitute for, nor a supplement to, rice--we were selling a new food, which did not look like rice--it did not taste like rice--it was not rice. It was fortunate that it cooked in about the same time--from 12 to 15 minutes; it was fortunate that it could be used with any indigenous supplements--meat, fish, vegetables, etc. Bulgur could be used as a form of porridge, as well as the main dish of the day, using the utensils already available, and the minimum of fuel. It is resistant to infestation. The reports came back faster and faster: "We like it. Can we continue to get it? Can we get more of it? It sticks to my ribs. I can work harder and longer with this new bulgur wheat." Bulgur wheat has been called many names--pilaf, kuss-kuss, and, one of the most significant, the name used in Taiwan: "Long Life Wheat."

During all this development period, we received encouragement and constructive help from the wheat growers of the states of Oregon and Washington. Later, the Great Plains Wheat, Inc. became actively interested in the countries they covered. As foreign merchandising offices were opened. they included bulgur in their sales efforts. As you will see a little later, this relationship with the wheat growers has proved to be a very happy, and I believe a useful and profitable arrangement for all concerned.

With the organization of the Food for Peace program in 1961, and the emphasis on the distribution of our surplus agricultural commodities, we found enthusiastic interest, not only in the Food for Peace program, but also from the various agencies of Agriculture, particularly the Foreign Agricultural Service. Without their support bulgur would not be where it is today. The Agency for International Development--"A.I.D."--has also actively distributed bulgur under their Title II program. For years the Voluntary Relief Agencies had requested, and documented their need for, bulgur. Frank LeRoux was appointed General Sales Manager of Foreign Agricultural Service, USDA, and with that sobering responsibility, he saw in bulgur a new outlet--a noncompetitive outlet--for some of the surplus wheat it was his responsibility to sell. The General Sales Manager coordinated the various interests, and spearheaded the presentation to Agriculture.

After a careful study, the Board of Commodity Credit Corporation approved a trial run of bulgur. to be distributed under Public Law 480, including Titles II and III, of some 60 million pounds a year. This was the maximum production of our plant at that time. We were the only producer of bulgur with any substantial capacity. It is not a pleasant situation when a company dealing with its Government has a monopoly on the product that is being sold. To avoid the stigma that might attach to such a situation, we submitted cost figures with assurances that we would sell bulgur for that entire year without any increase in price. The Government--C.C.C.--furnished the wheat so we had no market risk except for the byproduct. The processing cost to Government for the test was limited to the small manufacturing, packaging, and administration charges, and was paid for with wheat--no dollars were involved. We used the wheat surplus for the raw material, and to pay all expenses. It became

apparent early in the program that more bulgur would be needed than we were able to produce. We were asked by Government to determine the maximum immediately-available productive capacity, which we did. We realized the need for capacity, not only on the Pacific Coast, but on the Gulf, the Great Lakes, and tributary to the Atlantic Seaboard. We made available our method under license to interested producers and before long there were enough producers to ship bulgur from any of our ports to any destination in the world, cheaply and economically. During this period eight plants were activated. We doubled the capacity of our plant, and reports of the acceptability of bulgur came in from more and more countries--good reports--with growing enthusiasm.

I think you will be interested in the bulgur shipment schedule (Table 1) which shows the countries to which bulgur has been shipped since the beginning of the Food for Peace program in July 1961. At the bottom of the third page of this schedule you will note that the average shipments per month during the first year were approximately 5 million pounds, during the second year, 25 million pounds; in July 1963, 45 million pounds, in August 1963, 45 million pounds, September 1963--the end of a procurement period for the Voluntary Relief Agencies--1 million pounds, and in October 1963, 51 million pounds.

The totals during the first year were 59 million pounds; during the second year, 306 million pounds, and our estimate of the total for 1963 is 500 million pounds--1/2 billion pounds of bulgur.

You will note tremendous growth in certain countries: Taiwan, a little less than 900,000 pounds a month the first year, and, in the period from July-October 1963--with no shipments in September--an average of 5 million pounds a month, with an encouraging maximum of 10 million pounds in the month of August. Hong Kong is a disappointing market, and a market that should be a very fine one for bulgur. Vietnam averaged 670,000 pounds a month the first year, and in 1963 for July, 28 million pounds, August, 14 million pounds, and very little in September or October. The Malay Peninsula needs more work; although it shows growth, it is a very slow growth. The areas of West Africa are conspicuous for the small quantity of bulgur that has been shipped, the only exception being the Congo, which took 4 million pounds in October 1963, as compared with 20,000 a month the first year, and 620,000 a month the second year.

I particularly mention the African shipments, which I want to discuss in more detail a little later.

It is, however, gratifying to realize that our 1963 total projection, for all countries, of 500 million pounds, is almost 10 times as much as in 1961-1962, and almost double the shipments for the second year.

The smiles and disbelief which were evident when some of us with an enthusiastic faith in bulgur's crusade said it might reach 100 million bushels a year, have changed to, "You may do it, at that!"

Table 1.--Bulgur, total all agencies, shipped and scheduled for shipment
/In pounds/

Country of destination	First year July 1961/June 1962 Average per month	Second year July 1962/June 1963 Average per month	1963 Scheduled for shipment July	August	September	October
Korea	342,300	455,800	707,500	111,000		2,980,800
Ryukyus	209,900	823,500	988,000			4,159,700
Taiwan	868,400	5,229,200	2,548,600	10,248,800		6,469,200
Hong Kong	631,200	960,000		1,066,300		1,599,200
Macao		112,700		428,300		428,200
Philippines	111,100	727,600	840,200	2,382,500		3,095,000
Vietnam	670,300	6,455,800	28,659,800	13,875,000		256,000
Laos	47,200	106,300	375,000			375,000
Malaya	800	233,400		917,300		410,900
Singapore		23,600	265,300			265,300
Sarawak		17,200		123,500		1,014,500
Indonesia		31,000				178,000
East Pakistan	81,300	344,200				3,272,400
India	678,500	1,174,100	1,000,000	2,200,000		3,200,000
Nepal		11,000		154,300		
West Pakistan		228,200				1,235,000
Iran	29,200	6,200	195,800	16,200		183,000
Malagasy Republic		102,100		592,900		
Tanganyika		139,200				309,700
Rwandi-Burundi		60,500	120,400	276,000		276,000
Fr. Somaliland		7,000				
Ethiopia	73,700	128,600				
Aqaba		7,800				
Israel	16,200	25,700	176,900			
Jordan	31,500	43,000				15,000
Turkey	124,300	88,700	266,000			266,000

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Table 1.--Continued

Country of destination	First year July 1961/June 1962 Average per month	Second year July 1962/June 1963 Average per month	1963 Scheduled for shipment July	August	September	October
Greece	25,500	70,800	110,000			110,000
Yugoslavia		2,400		5,000		5,000
Poland	57,500	46,700				
Egypt	70,800	61,400	58,500			
Tunisia		515,900	892,300			1,152,300
North Borneo				89,500		89,500
Algeria		48,800				
Morocco	75,000	318,000	418,300			418,000
Senegal		363,900				789,000
Mauritania			727,800	292,700		1,350,000
Sierra Leone		63,600	295,000			
Liberia		14,100	67,500			
Ghana		85,800				
Dahomey	28,800	100,400	272,000			272,000
Nigeria		116,800		42,000		
Cameroons		2,000				
Congo	20,000	623,100	865,000			4,101,800
Grenada	2,700	4,400		17,000		
Jamaica	25,000	117,800		150,000		
Dominican Republic		743,700	1,525,000	2,611,000	440,900	990,000
Haiti	5,000	118,500		136,700		
Turks and Caicos		500				
Paraguay		117,300	885,000			
Brazil	87,100	1,176,200				3,530,000
Venezuela		162,700		1,895,000		2,895,000
Colombia	334,000	1,192,100		2,045,000		2,345,000
Ecuador		136,300	1,000,000			

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Table 1.--Continued

Country of destination	First year July 1961/June 1962 Average per month	Second year July 1962/June 1963 Average per month	1963 Scheduled for shipment July	August	September	October
Peru	75,700	738,000		591,700	760,600	
Bolivia	56,200	531,800	1,300,000	1,472,900		2,290,000
Chile	88,800	229,300		63,000		228,000
Honduras	8,300	45,500	182,000			
Guatemala	20,800	95,800		944,300		445,500
Mexico		127,500				
Nicaragua						300,000
Average per month	4,897,100	25,513,500	44,741,900	42,747,900	1,201,500	51,300,000
Total per year	58,765,200	306,161,600	July 1963/June 1964--Estimated--500,000,000			

You ladies and gentlemen are familiar with food. Think back over your experience. Have you ever seen a new food--for this is a truly new food--gain such tremendous popularity in such a short time? Even to me, it is almost unbelievable, and I have always had great faith in bulgur.

Distribution during this 3-year period has been largely through the Voluntary Relief Agencies in so-called "giveaway" programs. This has proved to be the most effective sampling campaign that the world has ever known. As sampling proves the popularity of the product, we must be prepared to move forcefully and aggressively into commercial distribution.

A trade association of bulgur processors, called Bulgur Associates, Inc. has been organized. We have joined forces with the wheat growers of the United States--the Western Wheat Associates, U.S.A., Inc, and the Great Plains Wheat, Inc. Both these groups have foreign representatives that cover--without duplication, although in some areas pretty thinly--the entire world. Their responsibility is to promote wheat and wheat products. They have been of great and effective value in the promotion of bulgur. They--and we--realized that there was need of someone to supplement their efforts--a specialist, spending all of his time on bulgur.

A committee was formed, consisting of two members from Western Wheat, two from Great Plains, and two from the processors. This is the Joint Bulgur Promotion Committee, which has the responsibility of merchandising bulgur in cooperation and coordination with the wheat offices in the various countries, and with our own Embassies and Agricultural and Commercial Attaches. The wheat groups are cooperators in Foreign Agricultural Service Market Development programs with foreign currencies available for their approved projects. They will allocate part of these foreign currencies to the Joint Bulgur Promotion Committee, and Bulgur Associates, Inc., by assessment of its members, will furnish the dollars needed to implement these funds, paying bulgur salaries, domestic expenses, etc.

In addition to all this, we are receiving splendid cooperation from all departments of Government. We have employed as Executive Secretary, Walter W. Graber, for many years Administrator of the Kansas Wheat Commission, a man who has made many foreign trips, and who is thoroughly familiar with, and sold on, bulgur. He has just returned from Egypt and Africa, where he has been working with our Embassies to try to secure more favorable consideration for bulgur, and alleviate the restrictive import quotas, tariffs, and embargoes. He was working with the Voluntary Relief Agencies, showing new uses of bulgur. He was also working with the Food Ministers and the procurement agencies in the various countries that he visited. Probably most important have been his activities with companies such as Unilever, Firestone, and Goodrich, which have very large operations in Africa. Also most important is the fact that these sales will be dollar sales, and dollar sales made to these companies that hold such a dominant position in the Congo, and in Liberia, will have an effect on the dollar imports of these countries, for other purposes.

The sampling program--the "giveaway" program--is now moving into the second and third phases, with our aim being the development of dollar sales. Until this is accomplished, we are only scratching the surface.

On this trip, calls were made in Brussels and Rome, enroute, with our promotional activities limited to Egypt, Nigeria, Liberia, and Sierra Leone. I must not pass Nigeria without reporting an interesting development whereby the Mobil Oil Company has been demonstrating cooking oil and oil stoves through the country by serving meals prepared on these stoves. They have 10 mobile trucks thus equipped. The Joint Bulgur Promotion Committee and Bulgur Associates, Inc. have made an arrangement by which we will furnish the demonstrators and the bulgur on a joint venture with Mobil Oil Company. This will give us wide coverage throughout the entire area.

In Liberia the Firestone Company sells rice through its own stores at 4 cents a pound; it costs them 8 cents a pound. Although they have only slightly in excess of 35,000 employees, they are feeding 250,000 people, inasmuch as the families and relatives of an employed Liberian share in his good fortune, and eat the 6 pounds per worker per week that is furnished, together with the 6 pounds for each adult dependent. Bulgur--a better food--will cost them approximately 6 cents a pound. We are sending samples and demonstrators into the area to prove the acceptability of bulgur, and have been assured that substantial dollar sales will follow.

In the Congo, where Unilever has 40,000 employees, they have purchased 5 tons of bulgur for testing in their own hospitals and controlled feeding areas, with a tentative order for 20,000 tons to be shipped for dollars, if approved.

We are leaving in Africa an American, experienced in foreign trade. He will be there for a sufficient length of time to employ, organize, and supervise the demonstrations and the feeding tests of bulgur.

Again referring to the list of countries receiving bulgur, total shipments since 1961 to the Congo have been about 5 million pounds, to Nigeria, less than 200,000 pounds, Liberia, less than 100,000 pounds, and Sierra Leone, about 250,000 pounds.

Nothing, I think, points up so clearly the need for quiet, persistent introduction, promotion, and demonstration of bulgur as the success, measured in orders, that resulted from the first trip of the representatives of our new organization into an area where bulgur is practically unknown. As we move from country to country and as we gain experience, our efforts will be more and more successful.

The Executive Secretary left October 19 for bulgur promotion at the Trade Fair in Lima, Peru, where a commercial sale has been made through a distributor who will make the product available for consumer purchases as a result of the demonstration and promotion at the Fair. He will then cover other important countries in Central and South America, returning to the United States the middle of December. Shortly after the first of the year, he will be going to the Orient. In each area where it is advisable, he will develop and leave an organization to carry on the specialized efforts for bulgur which will be coordinated by, and report to, the Wheat Group personnel in those various markets.

Great as has been the growth of bulgur, we are only scratching the surface. We have a fine sampling campaign. We must now follow up this sampling campaign and see that the product is available in normal channels of trade to the people who, we know, like it and want to buy it.

Bulgur Associates, Inc. has a research committee, which will work closely with the Regional Research Laboratories. Bulgur is good. We must be sure that it is as good, nutritious, and attractive as is possible to make it. We must be careful to make changes in the product only when it has been proved they will be beneficial. Bulgur is a good and acceptable food as it is; it is true with every successful merchandising program that many additives will be suggested for making a so-called "complete food"--to be tied to the bulgur coattails--or should we say apron strings? We must resist untried "improvements" which will increase the cost. We must recognize that an additive, perhaps needed in one area, would be unnecessary and wasteful in another. Let us be sure that we make bulgur as good, as wholesome, as palatable, as safe, and as cheap as it is possible. Let us encourage the recipient countries, with the help of our home economists, to develop their own recipes, using indigenous supplements--vegetables, sprouts, fish, meat, etc. If other surplus agricultural commodities are available from the United States, add those, or mix them, in the area of distribution, but only where needed. Let us avoid the glittering pitfall of trying to be all things to all people, at all times.

Domestically, bulgur has been approved for school lunches. The Civilian Defense authorized the production of bulgur wafers for their shelter program. It is available under the brand name "ALA" throughout the Western States, in supermarkets. Nationally, as "Old World Pilaf," it is available in gourmet shops. The processors are developing private sales, for dollars, in many countries. Although the value is small, the potential is great. Our course is clear:

1. Free distribution through the Voluntary Relief Agencies (our sampling program), and A.I.D.

2. Commercial sales, Government to Government, for foreign currencies under Public Law 480, Title I, and long-term credit dollars under Title IV. Titles I and IV will open markets presently closed to private trade by tariffs, embargoes, and currency restrictions.

3. Private sales by industry, for dollars. The time and success will depend upon our ingenuity and efforts. We have a new food that strengthens the people who eat it, and likewise strengthens the agricultural economy of the United States.

Ladies and gentlemen, let me close with the same thought with which we started. Many people within Government, many scientists, engineers, and technicians, many conscientious American workmen and supervisors, many producers and processors--and merchants--have contributed to the successful beginning of the bulgur program. Many more will be drawn in as time goes on.

May we enlist your interest and your support in this crusade.

WHEAT UTILIZATION IN USDA'S DONATION PROGRAMS

C. J. Maxey, Chief
Direct Distribution Branch, Food Distribution Division,
Agricultural Marketing Service, USDA, Washington, D. C.

Let me explain, first of all, that we have two kinds of food donation programs in the Department of Agriculture and that I am not going to say much about one of them at this time. Namely, the Food Stamp Program. But I do want to describe it very briefly.

The Food Stamp Program is essentially a means of donating food to needy families by donating additional income in the form of coupons that may be exchanged in the grocery store for food. The participating needy families exchange for coupons that amount of their income that (assuming they have an income) they would normally spend for food, and are given bonus coupons in proportion to the additional food needed by the family to provide a reasonably adequate diet.

Currently, this program is in a pilot stage, being in operation in only 40 counties and 3 cities in 22 states across the country and reaching, as of September, almost 348,000 persons. This contrasts with some 24 million persons who are benefiting from the Direct Distribution Program.

Any meaningful expansion of the Food Stamp Program must await action by the Congress. Time does not permit me to go beyond this very brief mention of the Food Stamp Program, but I will be here through today and will be pleased to answer questions regarding this program if any of you are further interested.

As mentioned, our other food donation program is called the Direct Distribution Program and it goes back to 1932 when Congress authorized the transfer of 40 million bushels of wheat to the Red Cross for donation to families on relief. In 1933 and 1934, pork and beef acquired by the Department of Agriculture as a drought relief measure, was donated through the Federal Emergency Relief Administration. And in August of 1935 the Congress authorized the Department of Agriculture to "encourage the domestic consumption of agricultural commodities or products thereof by diverting them, by payment of benefits or indemnities, or by other means, from the normal channels of trade and commerce."

The quote is from Section 32 of Public Law 320, which provides the basis for a food donation program that has been operating in this country, in some form of the other, for some 27 years. Section 416 of the Agricultural Act of 1949 (which is now more popularly referred to as Title III of Public Law 480), added to the Department's authority to donate foods in this country and extended its donation authority to include private welfare organizations who assist needy persons in foreign countries.

GPO 809-570-2

As could be predicted, the magnitude of the food donation programs has varied greatly over the years, in terms both of the persons benefiting and in the quantity of the food donated. As also could be predicted, the low point in the quantity of foods donated in this country came during the war years (1944 to be exact), when this figure stood at 283 million pounds as compared to a peak year of 2.5 billion pounds in 1941. In recent years, our donations have amounted to about 5 billion pounds annually, but about 3 billion of this has gone overseas.

Now, what part has wheat and its products played in all of this? Well, as I said, the very first food donation program consisted of 40 million bushels of wheat. Then, from 1936 through 1943 and from 1956 to date, wheat in some form was included in the Department's food donation program. There is no explanation apparent, as we look back over the statistics, for the differences in the quantities of wheat products that were donated from year to year. We note, for example, that in 1941 something over a half a million barrels of flour were distributed to over 14 million recipients while in 1939 almost one and a quarter million barrels were distributed to a million fewer recipients. In the last several years--that is, since 1956--the usage of flour in the donation program has steadily increased, until last fiscal year, when there was a reduction from fiscal year 1962 in the domestic program from 546 to 512 million pounds and in the foreign program from 1.369 to 1.213 billion, for a total reduction of 190 million pounds.

At the same time, however, there were increased donations of rolled wheat and bulgur in these programs of 217 million pounds; so the trend in wheat product usage in our donation program is still upward. The conclusion would have to be--in looking over the statistics--that wheat products are useful and welcome in the food donation program.

In view of this, one may ask the question: What were the circumstances that caused wheat products to be absent from the list of donated foods for the 12 years from 1944 through 1955? I can only suggest an answer. First, of course, is the fact that after the war the United States was indeed the granary of the world, and the wheat from the farms of this country was needed to keep many of the countries around the world from literal starvation. There was also the fact that for the 10 years from 1944 to 1954 unemployment and underemployment was not a serious problem here. Thus, it would appear that during this period there was not the necessary juxtaposition of want and plenty to create a public interest in the matter of food donations.

In 1954, however, the number of needy persons in family units who were receiving food donations increased to 1,100,000, up from only 100,000 the previous year. At the same time, the Department's inventory of wheat increased from less than 1/2 billion bushels in June of 1953 to over 3/4 billion bushels in June of 1954.

Then, in 1954, Congress amended Section 416 of the Agricultural Act of 1949 to permit the Department to pay reprocessing costs on the commodities it donated. Previously, commodities from Commodity Credit Corporation inventory

were donated on an "as is" basis, and so this amendment was ostensibly designed to encourage donations by putting the commodities in more usable and useful forms.

However, this did not change the situation with respect to wheat because the Department held--certainly with logic on its side--that the manufacture of wheat into flour was processing rather than reprocessing and, therefore, that this amendment did not authorize the donation of flour.

So, in August of 1955, the Congress passed special legislation which expressly obligated the Secretary of Agriculture to make up to $15 million worth of cornmeal and flour available to the needy persons of this country. In 1956, the Congress again amended Section 416, this time to clearly permit the payment of processing costs; and finally, in 1958 the Department was authorized to purchase flour outright instead of processing its wheat in order to donate it under Section 416. And this is how the matter stands today.

It is pretty clear, I think, that flour re-established its position on the list of foods available for donation only after several years of pulling and hauling between the Executive and Legislative Branches of Government. We call this, of course, the operation of the system of "checks and balances" that is inherent in our form of Government.

What was the area in which this "checking and balancing" took place? I can hazard an answer to this by quoting from a study published and distributed by the American Enterprise Institute for Public Policy Research entitled "Subsidized Food Consumption," which investigates the cause and effect of farm subsidies and farm surpluses:

> "From the first some voices were raised in doubt as to whether donation meant additional utilization. Congressman Clifford Hope of Kansas pointed out on the floor of the House on March 3, 1932, that the gift of grain to humans would displace purchases of flour.
>
> "Replacement, rather than additional consumption is particularly prevalent for such low-cost items as wheat flour.
>
> "It remains true, however, that when the Government donates from its inventory, the flour from, say, a million bushels of wheat it inhibits the sale of flour or bread to an appreciable though not measureable degree.
>
> "The donated wheat has high visibility. Hence the illusion that domestic donation of wheat is an effective means of reducing the Government's inventory of these products.
>
> "In the last analysis the food donation program functions more like an overall welfare program than like anything else."

It is clear, I think, from the foregoing that differences of opinion would arise between a person or a faction that believes that the donation program should be an effective means of reducing the Government's inventory of surplus wheat but is convinced that it is not, and another person or faction that views the donation program, if you please, as a highly visible means of making use of a highly visible food and is not a bit concerned that it may function like an overall welfare program. I do not think that it should surprise us that the Congress would be inclined toward the latter view, nor should we expect that the Executive and Legislative Branches need necessarily have different views on this matter. To the contrary, President Kennedy issued his first executive order just one day after his Inauguration, and it directed the Secretary of Agriculture to "Take immediate steps to expand and improve the program of food donation throughout the United States." And now, in the normal course of things, we find that there are those in Congress who maintain that in issuing this order the President abused his power and "as such (the order) was unconstitutional and illegal."

In any event, of the statements that I have quoted there is only one with which I would want to argue a little. And actually I do not believe that this statement is meant to say what the plain meaning of the words convey. (At least, what they convey to me.) This statement is: "Replacement, rather than additional consumption is prevalent for such low-cost items as wheat flour." I say that I do not believe that this statement means to say what it does because in another place in this study I find the following: "What the Department of Agriculture is doing with the domestic food donation program, in summary, is this: It is somewhat increasing utilization of its inventory of agricultural products and somewhat assisting farmers in finding new uses for their abundent products." And, certainly, I would not argue with this.

Surely, we would not contend that we get a pound-for-pound increase in utilization for all of the flour we donate. This would be flying in the face of reason. On the other hand, there is plenty of evidence to show that by our donation of flour we do get a net increase of consumption.

In the February 1963 issue of the Journal of the American Dietetic Association we find the report of an investigation of the Department's food donation program. In this investigation, data on the frequency and actual use of food by 60 recipient families in and around a small industrial community in Pennsylvania were collected. These 60 families consisted of 283 persons (for an average of 4.7 persons per family) and comprised about 20 percent of the recipients of donated food in that county. According to this report, "Baking was common. Bread was baked by 39 homemakers and averaged 6 loaves a week for these families. Rolls and biscuits were baked in 41 households. Twenty-four homemakers baked cookies regularly and 37 baked pies."

Further, the report says that the homemakers had no difficulty in using flour at the rate they received it--which in Pennsylvania, as in many other states, is 5 pounds per person per month. This would seem that the families in this sample (averaging as they do 4.7 persons), would receive 23.5 pounds per month.

Now, according to the USDA Household Food Consumption Survey of 1955, Report No. 2, entitled "Food Consumption of Households in the Northeast," urban and rural nonfarm households of two or more, having an income of less than $2,000 a year, used 2.08 pounds of flour and 0.46 pound of prepared flour mixes a week, or about 11 pounds a month.

This permits a conclusion that families will use twice as much flour when they get it free as they do when they have to buy it. Or, to put it another way, about 50 percent of the flour that is donated is in substitution for flour that would be purchased, while 50 percent results in increased utilization. This, I might add, confirms the findings of other studies.

Now, for the schools, which are the other large users of donated flour, we find according to a USDA Market Research Report entitled "The Market for Food in the Public Schools," that in 1958 all schools having lunch programs, whether they participated in the National School Lunch Program or not, purchased flour at the same per capita rate. At the same time, however, the amount of donated flour used per capita in the National School Lunch Schools was over six times the rate used in the other schools. There is an explanation for this, and it evolves from the fact that a school lunch program as operated under the National School Lunch Act is not just a restaurant being operated on school premises. I think that this fact--and the consequences that proceed from it--are quite implicit in the following paragraphs from the School Lunch Annual Report of the schools in Henrico County, Virginia:

> "In administering the school lunch program, the broad continuing goal has been improved physical and social well-being of the youth through good nutrition. This basic goal has served as a guide for the development of every phase of the program on a nonprofit yet self-sustaining basis. Well-planned lunches which meet one-third of the child's daily nutritional needs are made available to all students at a charge of 30 cents per lunch served. Those students who are unable to pay for their lunch receive the complete lunch free of charge with the cost absorbed by the school lunch program. Evidence of the effectiveness of the program is the rapid increase in the participation from 25 percent of the Average Daily Attendance in 1955 to 47 percent in 1963.
>
> "Sound financial management has been basic to meeting the rising costs of personal services and food and to hold the charge to the pupil 30 cents.
>
> "In addition to continuous on-the-job training in the individual schools a 1 day baking workshop was conducted... Not only did managers participate in making the varieties of bread but comparisons were made in costs and quality of breads made in schools and purchased breads."

In short, by increasing the use of flour in the schools' lunches, costs can be kept down; by keeping lunch costs down, participation can increase; and as participation increases, more flour can be used. And so, we have a rather "un-vicious" cycle.

I think that in all fairness I should point out, however, that the availability of cornmeal, butter, shortening, nonfat dry milk, dried eggs, peanut butter, and cheese in our donation program has greatly enhanced the value and utility of the donated flour. Conversely, of course, flour has added to the value and utility of these other products.

The point is, nevertheless, that the food donation program does, indeed, "somewhat increase" the utilization of flour even in our domestic program. It is generally conceded that the flour going into our foreign program is practically 100 percent increased utilization.

I think there is little doubt, too, that the rolled wheat we are donating, which amounted to almost 79 million pounds last fiscal year in our domestic donation program and 16 in the foreign, is almost all increased consumption.

I doubt that I need to say anything more, after Mr. Locke, about the use of bulgur in our foreign donation program. We have just gotten well underway in introducing bulgur in this country with some 25 states currently using this product in one or more of their donation programs.

We have been concerned not to "push" bulgur on users until they are prepared to use it properly and thus give it a fair trial. Consequently, and thanks in great part to the help we have received from the folks in the wheat industry, and particularly from the Kansas Wheat Commission and the Western Regional Research Laboratory, we have conducted quite an educational campaign on the use of bulgur. And we are now tabulating the results of a survey that should tell us how we have done. So far, it would appear that the results are encouraging.

However, we have not yet had anybody write in and ask us where he can buy some bulgur, as has been the case with rolled wheat. Quite frankly, I hope that when that first letter does arrive that there is a reasonably priced bulgur product readily available in the stores.

Since we do not usually hear from people unless they have a complaint, the nice comments we have received about our donated rolled wheat has been very pleasant. Whether this presages any large and growing market for rolled wheat in the future I could not say, but certainly a potential market would seem to be there.

On this point, I think that I would have to make the observation that over the years there has been more than one instance where the food trade has failed to follow up on the development of a potential market that was created by our donation program. In such instances, a great deal of the benefit and value of the program is lost.

This is all by way of saying that USDA's donation programs indeed, it seems to me, "somewhat assist farmers in finding new uses for their abundant products" in addition to "somewhat increasing the utilization of agricultural products."

And finally, they do something else. They answer the question of that irate citizen, and you would be surprised how many take the trouble to write us, who asks, "How can you pay millions of dollars a year on storage of food that is left to waste and molder while there are millions of persons in this country who go to bed hungry?" It does no good to explain to that person that donation is not an effective means of reducing the Government's inventory of wheat, nor would it be convincing to the lady who wrote in complaining that she had been cut off from receiving food donations in her community and said, "We weren't getting all that much; the cereal (rolled wheat I assume), butter, lard, and peanut butter was a great help. Also the flour." Thank you very much.

CROSSLINKED CEREAL XANTHATES IN PAPER PRODUCTS

RESEARCH PROGRAM AND CURRENT STATUS

C. E. Rist, Chief
Cereal Products Laboratory, Northern Utilization Research
and Development Division, USDA, Peoria, Illinois

Good opportunity exists for the development of new industrial uses for wheat and wheat products in the pulp and paper industry. The U.S. pulp and paper industry produced 37,648,273 tons of pulp and paper products in 1962. In this production over 1 billion pounds of starch were consumed. The largest percentage was from corn, with minor amounts from sorghum, wheat, and potatoes. Wheat starch has not been produced largely because of the normally higher price of wheat compared to corn and sorghum. If it were unnecessary to use refined starch as an additive for paper, either ground wheat grain or millfeed products might serve as a raw material, at least in the less refined pulp and paper products. The production of coarse paper for wrappings, sacks, and bags amounted to 4 million tons, and that of paperboard, including that used in corrugated boxes, was 17 million tons.

For the above coarser types of paper the four to five million tons of millfeed produced annually would be a potential source of raw material.

Industrial acceptance of any additive in papermaking is predicated upon its ability to impart improved properties to the paper, and to improve either its production or its use. Faster rates of production and runability of the paper machine with no breaks and with uniform quality are almost as important as improved paper quality. Improvements for which additives are used today include wet and dry tensile strength, crush resistance or high compression strength, stiffness in humid atmospheres, and elasticity or "give." In insulation board manufacture, additives are being sought that will have better insulation and that will allow a faster rate of production. Of course, higher insulation value can mean the requirement of less wood pulp to make a unit of insulation board.

As we have reported previously, we believe cereal xanthates, one of our new research products, offer good opportunity for the use of wheat products in making paper.

Cereal xanthates have been made from starch, flour, and bran by reacting them with carbon disulfide, alkali, and water as shown in Figure 1. When treated with an oxidizing agent such as sodium hypochlorite solution, which is available as a laundry bleach, cereal xanthates are crosslinked to form an insoluble product called cereal xanthide. This reaction is shown diagrammatically in Figure 2. When the crosslinking reaction is conducted in the presence of wood pulp used in papermaking, the mixture of wood pulp

and xanthide serves as the furnish for making paper. This can be carried out without much change in the normal papermaking operation.

During the past year we have made considerable progress in the production and evaluation of cereal xanthate papers in a small fourdrinier paper machine. Most emphasis has been given to studies of unbleached kraft papers of the type required in corrugated boxes because of the large consumption of such paper. First attention was given to developing a continuous xanthate production system. Starch was used in the experimental studies because it permits easier control and analysis of product. These studies have resulted in a rapid, continuous procedure for making starch xanthate additives suitable for improving strength properties of pulp and paper products.

Starch xanthates having degrees of substitution (D.S.) from 0.07 to 0.47 have been made in a small-scale continuous mixer-reactor system. Data were developed on the effect of (1) mole ratios of starch, CS_2 and aqueous NaOH, (2) order of addition, (3) temperature, and (4) discharge pressure on D.S., reaction efficiency, and power consumption. Following 2-minute mixing periods starch xanthates were discharged as viscous pastes of 53-61 percent solids. Conversion of CS_2 to xanthate was 87 and 80 percent complete, respectively, for starch xanthates of D.S. 0.07 and 0.17 as determined by analyses within 10 minutes after discharge. For products of D.S. 0.10-0.29 the conversion was 90-93 percent upon standing 1 hour after discharge. In general, maximum efficiency is favored by increasing the temperature, adding CS_2 to starch before NaOH, and using a high NaOH:CS_2 ratio.

The results of using wheat starch xanthates prepared in this process have been most encouraging in a recent series of linerboard papers made in the experimental paper machine. Linerboard is the sheet used to cover the corrugated sheet of a corrugated box. The results of the linerboard studies may be summarized as follows:

1. Machine Runs

   a. Pulp. An unbleached softwood kraft (sulfate) refined to a freeness of 540-ml. C.S. (Canadian Standard--most frequently used by industry) or 810-ml. S.R. (Schopper Riegler) was used.

   b. Preparation of Furnishes. The pulp furnishes were made up to 2.5 percent concentration and xanthate solutions (ca. 10 percent concentration--prepared in the Ko-Kneader) added at the various levels. Alum was then added at 2 percent level of addition (based on pulp). The furnish pH was adjusted to ca. 5.5 (sulfuric can be used) and a 2.5 percent solution of sodium hypochlorite (commercial bleach) added until excess oxidant was indicated by external spot testing. Control paper was made using pulp alone and pulp plus alum.

   c. Paper Products. Board weight paper was made having calipers in the range 10.0-12.2 mils. The linerboard weight was 180 grams per square meter or about 42 pounds per 1,000 square feet.

2. Freeness

The drainage characteristics of the unbleached kraft furnishes containing up to 20 percent (pulp basis) of xanthide were considered to be satisfactory. The furnishes in almost all cases (exception was xanthide of D.S. 0.22--no effect) drained more rapidly, which is desirable in speeding production. The extent to which the drainage was increased would probably not produce any formation problems on a high-speed machine in which the pulp suspensions are violently agitated until they are laid on the forming wire. Most starches and starch derivatives at levels of addition comparable to those employed here would have slowed the drainage. This is particularly true of unmodified starches and starch derivatives of high viscosity.

3. Mullen Burst

The Mullen burst test is probably the most widely used test in industry to judge quality of bag and board papers. The increases obtained in burst strength are of the order of 63 percent with incorporation of about 5 percent of xanthide of D.S. 0.07-0.13. The burst test measures both tensile and stretch properties.

4. Tensile

a. Dry. Improvements obtained in dry tensile are very good, and what has been said about the burst strength in regard to the general effectiveness of xanthides of D.S. 0.07-0.13 and their level of use applies here.

b. Wet. The increases obtained in wet tensile strength using 5-10 percent xanthide (D.S. 0.07-0.13) are excellent. The wet strength is of a permanent nature. The wet strength if determined immediately after preparation of the paper is lower than when such paper is allowed to "cure" at room temperature for periods of time of several months or for several hours at 105° C. Much is yet to be learned regarding this effect, but increases to the order of 20 percent have been obtained by such curing. The level of wet strength which has been obtained is comparable to that found with the thermosetting resins such as cationic urea formaldehyde and melamine formaldehyde.

5. Compression Resistance (Stiffness)

This property which is valuable in boxboard manufacture is presently obtained by making heavier weight boards. Rigidity of the paper when moist is a very desirable characteristic. There is no established or official testing procedure available. However, xanthide in board gives results which to the best of our knowledge are comparable to those reported with use of synthetic resins. Although water absorption is decreased by xanthide, there is little embrittlement. The results obtained on experimental machine-made paper when tested after being exposed to an atmosphere of 90 percent relative humidity show a crush strength equal to about

65 percent of the strength of the unxanthated control paper when tested at 50 percent relative humidity. Much remains, however, to be done in this area to resolve the practicality of the use of xanthides in paperboard to increase stiffness of boxes.

Experiments on the use of wheat flour xanthates in experimental insulation boards have also been made. Dispersions of flour xanthates of D.S. 0.19, 0.46, and 0.65 were blended at 0-20 percent concentrations with a commercial loblolly pine groundwood pulp. These furnishes were either oxidatively crosslinked with iodine or sodium hypochlorite or crosslinked with zinc salt and formed into 0.5-inch thick insulating boards.

Zinc salt proved to be the most effective crosslinking agent studied. As little as 10 percent crosslinked flour was sufficient to impart dry strengths three times that of the control. Drainage characteristics were acceptable, and retention was 100 percent if furnishes were crosslinked at an 8 percent consistency. Although experimental boards had densities as much as 4 pounds per cubic foot less than commercial boards, the strengths were nearly equivalent or higher. Some sizing effects were evident, but wet-strength improvement as observed in fine paper, however, did not develop in board.

Flour crosslinked with zinc ion produces strength increases directly proportional to the flour content in the board over the range studied. Even at the highest levels of application studied, no maximum strength value was reached. Therefore, higher application levels than used here may be feasible.

Data developed in this preliminary study have demonstrated the considerable promise of crosslinked flour as an insulating board component to improve strength properties. The method employed to add flour to the furnishes, followed by crosslinking to cause precipitation in the presence of wood fibers, resulted in significant strength improvement in boards. Practical results must await further studies, now in progress, on new techniques for incorporating crosslinked flour into board furnishes.

Several types and grades of wood pulp, both with and without addition of asphalt are used in making insulation board. Experiments will be conducted to learn the behavior of flour xanthates with different commercial pulps.

Current Research and Problems

Considerable work remains in making experimental papers and in evaluation of all production factors, physical properties of the product, and stability under different environments.

The overall development of cereal xanthates as additives for the improvement of paper and paperboard requires investigation of many factors important to their production and use. The major areas now being studied in order to provide adequate answers are outlined in Figure 3.

Preparation of Xanthates and Xanthides

$$ROH + NaOH + CS_2 \longrightarrow ROCSSNa$$

xanthate

$$2\ ROCSSNa + \text{Oxidizing Agent} \longrightarrow ROCS{-}SCOR$$

xanthide

Fig. 1

Crosslinking and Intramolecular Coupling

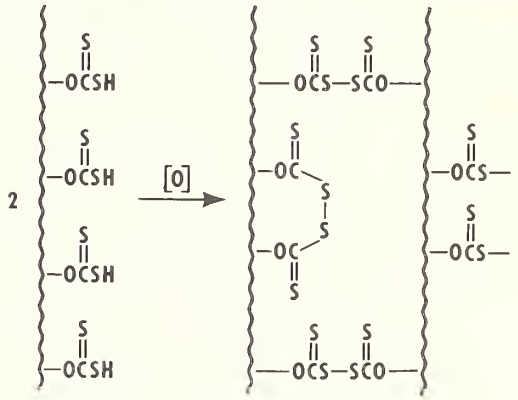

Fig. 2

Cereal Xanthates

Current Emphasis

- Handsheet and 10-inch fourdrinier data.
- Small scale xanthation process.
- High humidity resistant linerboard, insulation board-furnishes & crosslinking agents.
- Active *ex situ* xanthide.
- Fundamental chemistry of xanthation and C/L reactions.
- Eng. design cost data, trial quantities.

Problems

- Application in existing paper processes.
- Studies on stability in paper.
- Performance with variety of pulps for principal paper products.
- Development of *ex situ* process.
- Industrial evaluation.

Fig. 3

OBSERVATIONS ON RELATION BETWEEN PROTEIN RELEASE AND CONDITIONING IN THE MILLING OF WHEAT--LABORATORY STUDIES

M. J. Wolf, Head
Cereal Microscopy and Quality Investigations, Cereal Properties Laboratory, Northern Utilization Research and Development Division, USDA, Peoria, Illinois

Summary

The effect of conditioning of wheat on endosperm breakdown is ordinarily studied by air classification of the flours obtained after milling or regrinding of the as-is flour. Protein content of the fractions is determined to note the redistribution of the protein. Microscopically, the various fractions are seen to be mixtures of free starch, free protein, and endosperm particles made up of adhering starch and protein.

Kjeldahl analysis does not distinguish between free protein and protein bound to starch. Consequently, a clear picture of endosperm breakdown into the basic particles cannot be obtained by air classification and Kjeldahl analysis alone.

It would be useful to be able to estimate the proportion of free protein, free starch, and of endosperm particles released as the result of wheat conditioning treatments. Some preliminary work was done by microscopic methods to estimate degree of endosperm breakdown.

Particles of as-is or reground flours were classified microscopically into three basic groups: endosperm, free starch, and free protein. Frequency distributions of each of these three groups were determined by microscopic sizing in flours from conditioned wheats. Calculations from the microscopic data provide an estimate, on a weight basis, of the composition of a flour with respect to the three basic groups of particles.

In Wichita wheat (HRW) conditioning at temperatures from room temperature to about 60° C. had little effect on protein release. In general, conditioning at low moisture levels appeared to have a more pronounced effect on protein release than moderately high temperature treatment.

Highest free protein in flour was found in grain dried down to about 8 percent moisture before milling. As the tempering moisture is increased, average flour particle size increases and free protein decreases.

Regrinding of flour had a marked effect on protein release. As much as 9 percent free protein was found in reground flour from grain dried down to 8 to 10 percent moisture before milling (protein content of the original wheat was about 17 percent by Kjeldahl analysis). This flour before regrinding had about 6 percent free protein.

Along with the work on conditioning and protein release, studies are being made of the fine structure of wheat endosperm, particularly with

reference to the aleurone layer and to the starch-protein interface in the starchy endosperm. These are the areas which have a direct bearing on the problems of bran cleanup and protein release.

Numerous plasmodesmata were found in the inner and radial walls of the aleurone layer, but not in the outer walls. They were stained moderately by osmium tetroxide indicating presence of some lipid material. At moisture levels of 11 to 17 percent, aleurone granules containing one or more globoids which stained heavily with osmium tetroxide, were surrounded by a band of sphaerosomes. There was no evidence of a continuous membrane at these moisture levels.

A thin osmiophilic layer about 0.2 to 0.5 micron thick is frequently found in the protein directly over the periphery of starch granules. The layer usually only partially covers the starch granules. This material was not found over all starch granules. No detail has as yet been observed in this band. Work is continuing on the nature of this material and its relation, if any, to protein release.

Inclusions of unknown composition, osmiophilic bodies, and small starch granules occur frequently in the interstitial protein between starch granules. These are probably derived from protoplasmic bodies of the original immature endosperm cells.

Development of wheat endosperm cells is being studied to aid in the interpretation of structures occurring in mature tissues.

AIR-CLASSIFICATION RESPONSE OF FLOURS FROM HARD RED WINTER WHEAT VARIETIES GROWN UNDER DIFFERENT FERTILIZER LEVELS

A. C. Stringfellow, Chemical Engineer
Engineering and Development Laboratory, Northern Utilization Research and Development Division, USDA, Peoria, Illinois

Investigations of fine grinding and air classification of wheat flour at the Northern Regional Research Laboratory have shown several differences in response. Among these are included: how soft differs from hard; how different varieties in the same class vary; and, how the same variety grown in the same area but in different years varies when there have been changes in climatic conditions. In addition to these, it would be desirable to know how the use of different fertilizer levels might affect the air classification of flour.

Recent studies at the Northern Regional Research Laboratory were based on this aspect of wheat flour response to air classification. They covered popular hard red winter wheats grown in Oklahoma by the Experiment Station under the supervision of Prof. A. M. Schlehuber during the 1961 season.

Materials and Methods

Five different HRW varieties were each grown at seven different fertilizer levels (Table 1). The five varieties can be considered as only

Table 1.--Oklahoma HRW Wheats

Five varieties	Seven fertilizer levels	
Hardness:	"A" Arrangement	"B" Arrangement
Minimum	A-1	Increasing NITROGEN Order
Concho	One-Component Fertilizer	
Triumph	$N_2 - P_2O_5 - K$	$N_2 - P_2O_5 - K$
Intermediate	0 - 40 - 0	0 - 0 - 0
Comanche	0 - 0 - 0	0 - 40 - 0
	40 - 0 - 0	20 - 40 - 0
Maximum		
Pawnee	A-2	40 - 80 - 0
Ponca	Two-Component Fertilizer	40 - 40 - 0
	20 - 40 - 0	40 - 0 - 0
	40 - 80 - 0	80 - 40 - 0
	40 - 40 - 0	
	80 - 40 - 0	

three general groups with regard to hardness as indicated. Concho and Triumph had minimum wheat protein, maximum grain yield. Pawnee and Ponca were just the reverse, and had maximum wheat protein, minimum grain yield. Comanche data placed it in the intermediate position shown.

The particular fertilizer levels used in this series are shown in the center and right-hand columns. Two reference levels are indicated by underlining: the 0 - 0 - 0 or unfertilized; and the 40 - 40 - 0 or balanced, normal fertilizer. For comparative purposes, the seven levels can be considered in two ways, as shown by columns "A" and "B." The A-1 or one-component grouping includes three fertilizer levels; phosphorus only, unfertilized, and nitrogen only. The A-2 or two-component grouping includes four fertilizer levels arranged in order of increasing nitrogen. The other arrangement is shown in the right-hand or "B" column. It starts with the unfertilized and is arranged in terms of increasing nitrogen. The underlined 40 in the center or P_2O_5 position indicates that it is often held constant at this value.

The 35 wheat samples were furnished in 15-pound lots, so a special procedure was required to handle these small amounts. A conventional Buhler mill was used to prepare straight grade flour at 68 percent extraction from each of the samples after they had received regular cleaning and tempering. This yielded about 10 pounds of flour from each wheat sample. The flour was then divided into two 5-pound lots, one to be air classified on an as-milled basis and the other to be air classified after fine grinding by one pass through the Alpine pin mill at 18,000 r.p.m.

All of the flour fractionations were done with a laboratory model Pillsbury classifier. The entire flour sample was fed to the unit at its lowest cut point, and the resulting finest or high-protein fraction taken off. The classifier was readjusted to a slightly coarser setting and a two-part separation again made with the coarse fraction just obtained. This repetitive procedure was followed through four cycles or settings to produce four sized fractions and one coarse residue for each of the 70 flour samples fractionated.

For each classification the original flour plus the five individual fractions were analyzed for moisture, protein, ash, and maltose value by AACC methods. Protein shift was calculated from the protein values for the individual, separated fractions. It equals the sum of the protein shifted out of the lower protein fractions and the protein shifted into the higher protein fractions.

Results and Discussion

The wheat samples furnished by the experiment station were produced under quite a wide range of fertilizer levels, so it is to be expected that there might be variations in the protein content of the whole grain and in the yields.

Table 2 shows protein contents, and Table 3 shows yields for these

Table 2.--Protein content of five wheat varieties from seven fertilizer treatments, 1961, Perkins, Oklahoma
(% Protein = % N x 5.7, 14% H_2O Basis)

Fertilizer treatments			Varieties					Average
N	P_2O_5	K	Concho	Triumph	Comanche	Pawnee	Ponca	
0	0	0	10.2	10.8	10.7	11.0	10.8	10.7
0	40	0	9.4	9.4	9.6	10.8	9.7	9.8
20	40	0	10.1	10.2	11.2	11.7	10.7	10.8
40	80	0	10.8	10.8	10.8	11.5	12.0	11.2
40	40	0	11.4	12.2	11.6	12.4	11.5	11.8
40	0	0	11.5	13.1	12.7	13.0	12.4	12.5
80	40	0	12.4	13.6	13.0	13.7	13.6	13.3
Average			10.8	11.4	11.4	12.0	11.5	

Source: Reference 5 and personal communication from A. M. Schlehuber.

Table 3.--Yield of five wheat varieties from seven fertilizer treatments, 1961, Perkins, Oklahoma

Fertilizer treatments			Yield, bushels per acre					Average
N	P_2O_5	K	Concho	Triumph	Comanche	Pawnee	Ponca	
0	0	0	32.2	32.1	28.6	25.9	28.3	29.4
0	40	0	30.9	31.1	31.0	28.1	26.9	29.6
20	40	0	35.5	37.8	35.2	29.2	33.4	34.2
40	80	0	38.7	41.8	35.6	32.8	35.5	36.9
40	40	0	37.7	38.3	34.1	31.7	33.4	35.0
40	0	0	34.1	33.4	30.7	25.3	31.0	30.9
80	40	0	38.6	38.8	34.1	31.5	34.1	35.4
Average			35.4	36.2	32.8	29.2	31.8	

Source: Reference 5 and personal communication from A. M. Schlehuber.

Perkins, Oklahoma wheats furnished by Prof. A. M. Schlehuber and described in the agronomy report, "Fertilizing Wheat for Yield and Quality" (5).

Figure 1 was prepared from the agronomy data for the three representative varieties Triumph, Comanche, and Pawnee in order to show trends related to the values, and depicted by the elevation and slopes of the lines with respect to each other and to the horizontal reference line. The left half shows single-component fertilizers arranged around the zero fertilizer level; the right half shows two-component fertilizers with the 40 - 40 - 0 as the center point. Protein is shown by the upper, solid lines, and yield

by the lower, heavy broken lines. The thin, horizontal, broken line serves as a reference line; it is the wheat protein content of zero fertilizer level in each case.

First, consider the solid protein lines. Disregarding, 40 - 80 - 0, it can be noted that the plots on both halves of Figure 1 all show positive slopes, indicating increased wheat protein when nitrogen is increased. In regard to yield, the broken lines are essentially flat, and indicate that the yield does not change much with respect to the zero level in the A-1 grouping, or to the 40 - 40 level in the A-2 grouping. However, the yield level at 40 - 40 - 0 is always greater than that at 0 - 0 - 0; and, for the three typical varieties raised with two-component fertilizer, Triumph yielded highest, an average of 39.2 bushels per acre, Comanche averaged 34.8, and Pawnee, the lowest, averaged 31.3.

Figure 2 shows variations in the protein content for the straight-grade, Buhler-milled flour from Triumph and Ponca, these being typical of the five varieties studied. Protein values are shown on the left, and along the bottom are shown the fertilizer levels in order of increasing nitrogen. Buhler-milled flour is shown by the broken line, and the solid line shows the higher values for the original grain.

It was noted that the protein values always dropped down from the starting or zero level when phosphorus only was applied, then proceeded upward as the nitrogen increased. The two lines parallel each other and indicate a general similarity at the various levels. The protein for Triumph flour varied from 8.2 percent to 12.6 percent; and the protein for Ponca flour varied from 8.9 percent to 12.8 percent. The total range in protein content for the as-milled flours was from 8.2 percent to 12.8 percent.

Figure 3 shows a clearer, simplified form of the plot for flour protein vs. fertilizer for Concho HRW wheat flour. It shows original, as well as minimum and maximum flour proteins, and where these occur with regard to fertilizer level. It is typical of a consistent trend observed in all five wheats used in these studies.

Tables 4, 5, and 6 show summary information from air classification of flours from three of the five varieties. Concho represents minimum hardness HRW, Comanche represents intermediate, and Ponca is typical of the higher hardness. The fertilizer levels are shown as the "A" arrangement, as described in Table 1, with single-component fertilizers given first and then followed by two-component fertilizers. The 0 - 0 - 0 and the 40 - 40 - 0 levels are underlined to indicate that these are reference levels.

In Table 4, when using Concho the reference fertilizer levels of 0 - 0 - 0 and 40 - 40 - 0 showed 32.2 bushels per acre, 9.8 percent flour protein, and 37.7 bushels per acre, 10.5 percent flour protein, respectively. High and low protein fractions from classified flour for the same two levels were quite similar, and averaged 27.4 percent and 5.9 percent with protein shift approximately 54 percent.

Table 4.--Air classification of Oklahoma HRW wheats

/Concho/

Fertilizer level	Wheat yield bu/A	Straight flour protein 1/	Flour fractionations: High protein	Low protein	Coarse residue	Protein shift
		% P	% P	% P	% Y	%
0 - 40 - 0	30.9	8.4	22.8	5.1	21.6	50.6
0 - 0 - 0	32.2	9.8	26.8	5.7	20.1	53.5
40 - 0 - 0	34.1	9.9	28.4	5.4	18.0	60.7
20 - 40 - 0	35.5	8.8	23.6	5.2	20.3	51.8
40 - 80 - 0	38.7	9.9	26.2	5.7	21.5	53.3
40 - 40 - 0	37.7	10.5	27.9	6.1	19.7	54.6
80 - 40 - 0	38.6	11.6	30.7	6.5	18.0	57.2

1/ Buhler milled.

Table 5.--Air classification of Oklahoma HRW wheats

/Comanche/

Fertilizer level	Wheat yield bu/A	Straight flour protein 1/	Flour fractionations: High protein	Low protein	Coarse residue	Protein shift
		% P	% P	% P	% Y	%
0 - 40 - 0	31.0	8.7	18.2	5.7	27.7	35.0
0 - 0 - 0	28.6	9.4	20.1	6.0	28.2	35.8
40 - 0 - 0	30.7	11.4	23.3	7.4	25.0	34.6
20 - 40 - 0	35.2	10.5	22.8	7.2	26.5	33.8
40 - 80 - 0	35.6	9.7	20.6	6.1	26.5	35.5
40 - 40 - 0	34.1	10.5	22.7	6.9	26.0	35.9
80 - 40 - 0	34.1	12.2	25.5	8.1	22.9	35.1

1/ Buhler milled.

Table 5 for Comanche shows that 40 - 40 - 0 fertilizer yielded 34.1 bu. per acre, 10.5 percent flour protein, as compared to 28.6 bu. per acre, 9.4 percent flour protein for unfertilized. Both gave essentially 35.8

Table 6.--Air classification of Oklahoma HRW wheats

/Ponca/

Fertilizer level	Wheat yield bu/A	Straight flour 1/ protein	Flour fractionations			
			High protein	Low protein	Coarse residue	Protein shift
		% P	% P	% P	% Y	%
0 - 40 - 0	26.9	8.9	18.2	5.9	31.8	25.2
0 - 0 - 0	28.3	9.4	20.1	6.5	30.6	28.2
40 - 0 - 0	31.0	11.7	26.4	7.7	26.7	33.9
20 - 40 - 0	33.4	9.4	19.6	6.3	29.2	28.6
40 - 80 - 0	35.5	11.1	23.0	7.5	29.0	29.1
40 - 40 - 0	33.4	10.7	22.5	7.0	28.1	28.8
80 - 40 - 0	34.1	12.8	26.8	8.2	26.9	29.5

1/ Buhler milled.

protein shift. High-protein fractions at the reference levels averaged 21.4 percent protein, and low-protein fractions, 6.4 percent. This variety was least affected by changes in fertilizer level.

Ponca, the hardest variety in this group, is given in Table 6 and showed the lowest average protein shift at the reference levels, 28.5 percent. Unfertilized Ponca produced 28.3 bushels per acre, 9.4 percent flour protein; and a level of 40 - 40 - 0 produced 33.4 bushels per acre, 10.7 percent flour protein. At these levels, high-protein fractions averaged 21.3 percent, and low-protein fractions averaged 6.8 percent.

All the straight flours had nearly the same percentage of protein when 40 - 40 - 0 was used, ranging from 10.5 percent to 11.1 percent, but those from the harder varieties gave lower protein shifts. The extent of variations in grain yield and protein, as well as protein shift, depended upon the amount of the fertilizer change. Changes in protein content of the wheat flour were greater than yield changes. The grain yields for any given variety were close to one of two levels, a lower one for single-component fertilizer and an upper one for two-component fertilizer.

Phosphorus alone was not as beneficial as when used in conjunction with nitrogen. This was indicated by minimum values for grain yield, wheat and flour protein, and protein shift when only phosphorus was added. Starchy fractions of lowest protein content were obtained when only phosphorus was used, but it will be noted that the parent flours were also lowest in protein content.

Balanced fertilizer like 40 - 40 - 0 gave good values for grain yield, wheat and flour protein, and protein shift at levels dependent upon the particular variety. The softest variety, Concho, showed most improvement in protein shift as the total quantity of applied fertilizer increased. Highest values for wheat and flour protein were obtained with fertilization at the 80 - 40 - 0 level, but the incremental gain would need to be evaluated in terms of the extra fertilizer cost to find out if it was economical.

In order to make better simultaneous comparisons of the results from all five hard red winter varieties, this summary information has been put on the plots shown in Figures 4, 5, and 6, which will clearly illustrate the relationships for high- and low-protein values, and also for protein shifting.

The bar charts in Figure 4 represent variations in high- and low-protein fractions at various fertilizer levels for each of the varieties. The shaded upper sections represent the variations. Protein contents were always highest for 80 - 40 - 0 and lowest for 0 - 40 - 0. The "X" and "O" in the shaded ends represent 40 - 40 - 0 and 0 - 0 - 0, respectively. The "X" and "O" in the lower part of the tall bars represent the protein contents of the as-milled flours at the 40 - 40 - 0 and 0 - 0 - 0 fertilizer levels, respectively.

The range in values for high-protein fractions averaged 7.4 percent (average of shaded tops of tall bars), whereas the range of values for low-protein fractions averaged 2.0 percent (average of shaded tops of short bars).

Figure 5 shows how each of the five varieties varies in protein shift as the nitrogen content of the fertilizer is increased. Disregarding the 80 - 40 - 0 level, the same general upward pattern is observed as for the protein content of the flour shown in Figure 3. Concho and Triumph show the highest values of protein shifting, with Pawnee and Ponca the lowest. Comanche is between these groups and changed very little in protein shift with change in fertilizer level.

Another arrangement of protein shift is shown in Figure 6 for the five varieties. The left half shows results for single-component fertilizer and the relationship to 0 - 0 - 0; the right half shows various ratio forms of two-component fertilizers related to 40 - 40 - 0. It is clearly apparent that Concho, Triumph, and Ponca showed the most change in protein shift due to variation in fertilizer.

Four concluding statements may be made as a result of the observations on the effect of fertilizer level on air classification:

1. The hard red winter wheats of minimum hardness were affected more by fertilizer changes than the harder ones,

2. Modest increases in nitrogen fertilizer produced moderate increases in flour protein, protein shift and grain yield,

3. Phosphorus aided the grain yield but had a diminishing effect on protein and protein shift,

4. Protein shifting was influenced much more by changes in variety than by changes in fertilizer.

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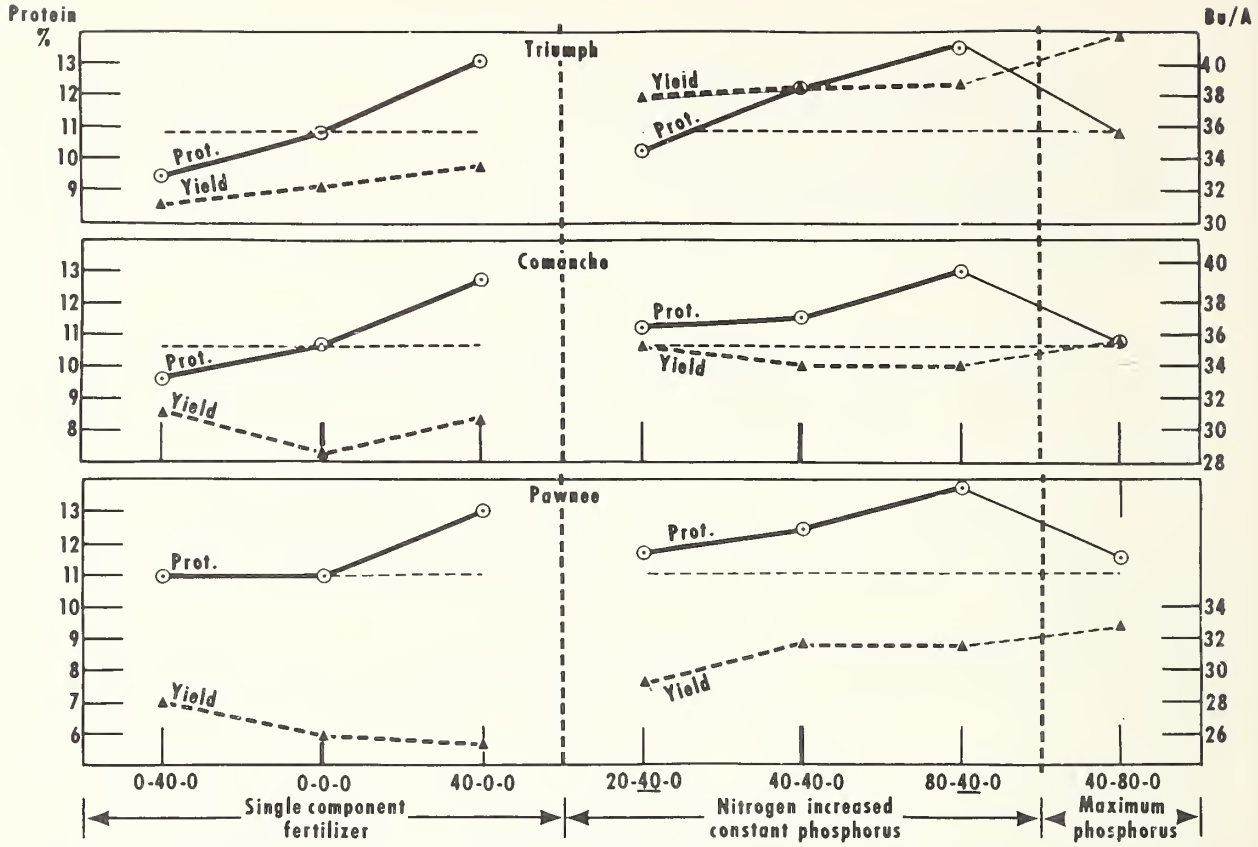

Fig. 1 Wheat protein and grain yield vs. fertilizer level

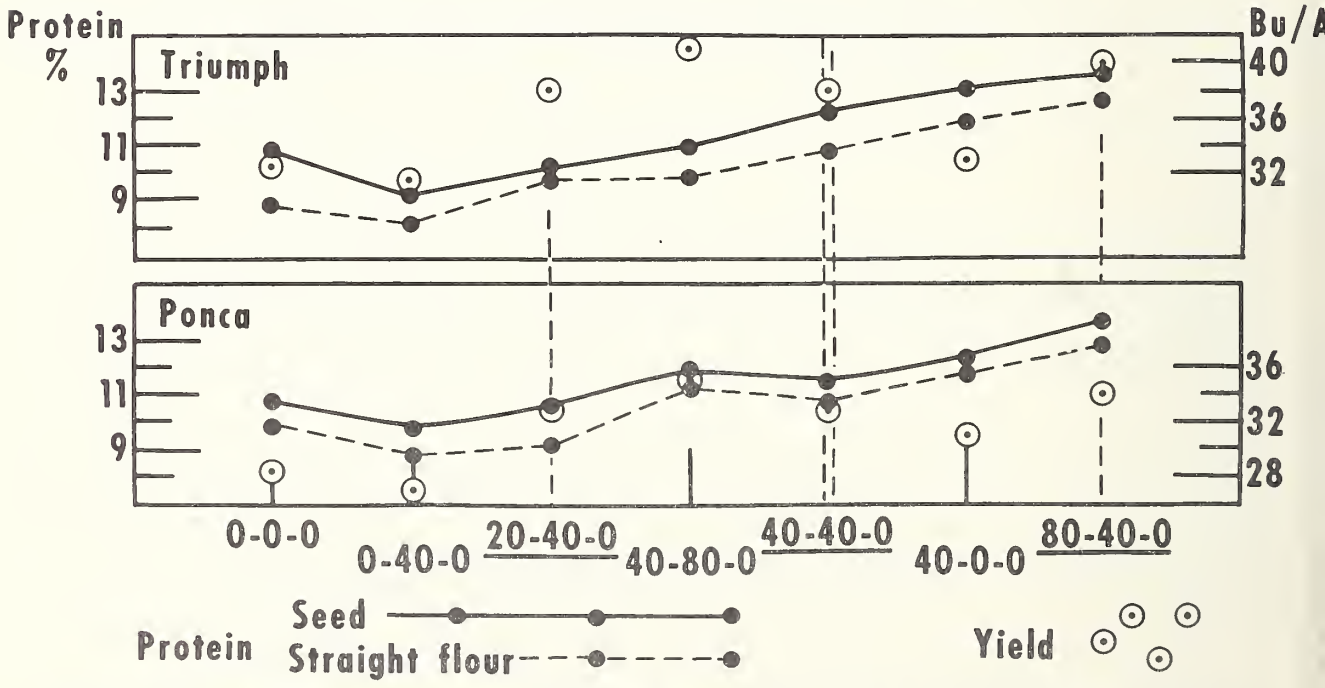

Fig. 2 Oklahoma HRW wheat and flour protein, and grain yield

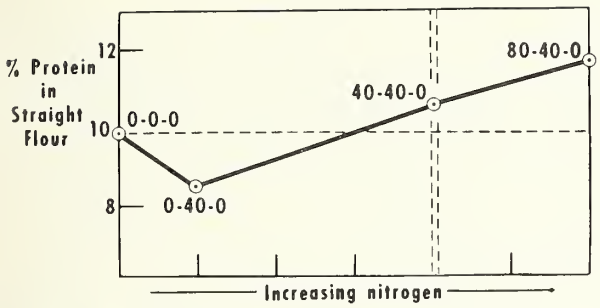

Fig. 3 Protein content vs. fertilizer level Concho HRW wheat flour

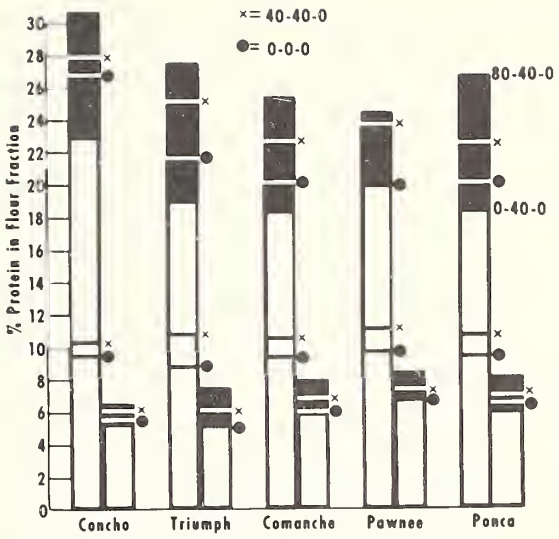

Fig. 4 Variations in high and low protein fractions

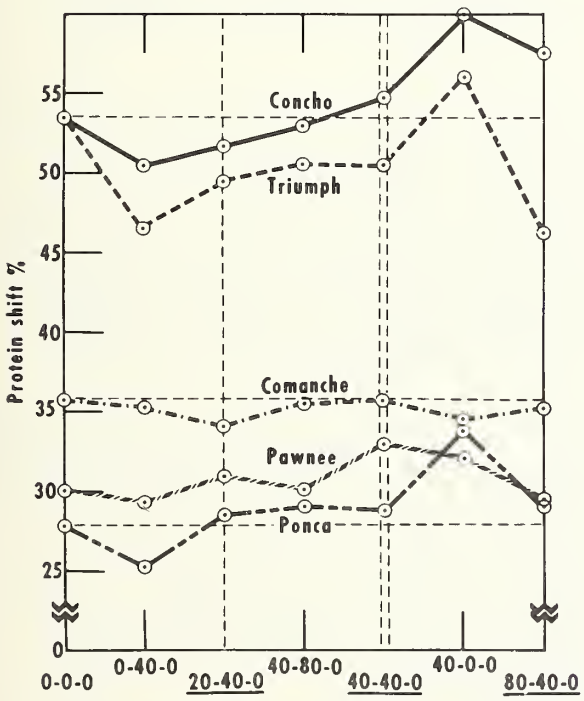

Fig. 5

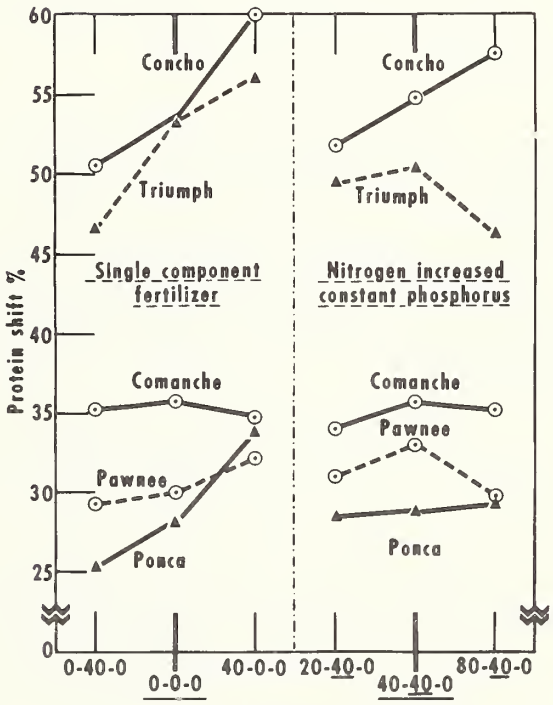

Fig. 6

Protein shift vs. fertilizer level

ENZYMATIC MODIFICATION OF WHEAT FLOUR

R. W. Jackson, Chief
Fermentation Laboratory, Northern Utilization Research and Development Division, USDA, Peoria, Illinois

The treatment of starches with enzymes and other agents for the preparation of paper-sizing material and coating adhesives has long been practiced. Raw starch, in itself, is not suitable for many large-scale adhesive applications because the viscosity of solutions of normal solids content is extremely high and free-flowing adhesives are not obtained. However, this disadvantage can be overcome, and experience has shown that practically any of the common natural starches can be altered to meet the requirements for a wide variety of adhesive applications. In surface sizing of paper, simply a solution of the modified starch is itself applied, whereas in paper coating the modified starch is employed to adhere a mixture of clay and pigment to the paper surface. Over a billion pounds of starch are consumed annually in the U. S. paper industry, and, of this, nearly half is used as surface sizing and coating adhesive. Both these applications require starches that have been modified to reduce paste viscosity.

The modification of starches is carried out by several different techniques. The more important for paper sizing are oxidation, enzyme treatment and heating.

The treatment of starches with enzymes in the preparation of adhesives has many advantages. Aside from the low cost of the treating agent, the enzyme method has tremendous flexibility. The solids content of the size or adhesive can be manipulated, amount of enzyme varied, pH controlled and the time and temperature schedule adjusted to suit particular needs. The final viscosity will depend, when other factors are held constant, on the amount of enzyme used. When, during cooking, the desired viscosity has been reached, the enzyme is inactivated by raising the temperature or adding a suitable chemical.

Currently no enzyme-converted wheat flours are used for surface sizing or coating adhesive in paper manufacture, but several paper companies have recently expressed interest. They would like to have available information on the enzyme conversion of cereal flours for use as sizes and coating adhesives. The conversion of wheat flour into products of desired viscosity is, of course, more complicated than the conversion of starch because the protein in wheat flour must also be modified. Both the protein and the starch must be changed into dispersible products, with sufficiently high and, preferably uniform, molecular weight distribution.

Enzymes that attack proteins, i.e., the proteolytic enzymes, are to be contrasted with enzymes that attack starch, the amylolytic enzymes. Therefore the problem of modifying wheat flour for use as an adhesive in sizing and coating operations was approached with both kinds of enzyme in mind. We are, of course, much interested in capitalizing on the protein in flour and gaining advantage from it, if possible, for our purpose.

A variety of proteolytic enzymes was examined for their ability to degrade a commercial vital wheat gluten. This was a starch-free sample of the water-insoluble protein of flour. The enzymes tested were commercial products from various animal, plant, and microbiological sources.

In Table 1 we see a list of eight proteolytic enzymes tried and the

Table 1.--Effect of proteolytic enzymes on wheat gluten

Enzyme	Protein solubilized	Dialyzable	Non-dialyzable
	%	%	%
Subtilisin	89.2	79.7	9.5
Pepsin	76.8	22.9	53.9
Trypsin	27.9	16.1	11.7
Papain	67.0	64.9	2.1
P-11	80.8	66.0	14.8
P-41	84.2	73.8	10.4
P-33	68.4	56.3	12.1
Pan protease	91.9	84.8	7.1

protein solubilized as a result of their action. Also a breakdown as to dialyzable and non-dialyzable, depending on whether the split products passed or did not pass through a cellophane membrane. From this table we see that pepsin was the only enzyme which solubilized gluten without splitting the protein into small units. Seventy-seven percent of the gluten was solubilized and 54 percent was non-dialyzable. On the other hand, subtilisin, like most of the other enzymes, solubilized a high percentage of the gluten with only a small fraction non-dialyzable, indicating that most of the protein had small molecular weight.

Experiments were also conducted on the amylase treatment of wheat flour. The flour employed was from Genesee soft white winter wheat and contained 7 percent protein. The enzymes employed were of bacterial and fungal origin. Each enzyme preparation was first assayed to establish an arbitary level of activity for conversion of the starch to the desired viscosity. In general, the viscosity should be in a range of 1000-5000 centipoises as measured on a 20 percent paste with a Brookfield viscometer at 25° C.

Table 2 presents the eight amylolytic enzymes employed and starch

Table 2.--Effect of amylolytic enzymes on starch in wheat flour

Enzyme (commercial)	Amount (per 60 g. flour)	Carbohydrate solubilized %	Dialyzable carbohydrate %	Non-dialyzable carbohydrate %
α-amylase	25 µg.	97	17	83
J-25	5.5 mg.	86	31.0	55.0
A-4	14 mg.	80	20.0	60.0
R-33	13 mg.	74	28.9	45.1
P-11	400 mg.	77	25.4	51.6
P-41	60 mg.	77	20.0	57.0
Vanzyme	50 mg.	82	58.2	23.8
R-39	25 mg.	80	36.0	44.0

solubilized or dispersed as a result of their action. In most cases the starch was 70-80 percent dispersed. Crystalline bacterial α-amylase gave best results; it solubilized 97 percent of the starch of which only 17 percent was dialyzable. This enzyme was chosen for our preliminary investigations because of its relatively high degree of purity and reproducibility of action.

Although the presence of amylolytic and proteolytic enzymes in flour has been known for a long time, it was only recently that we came to appreciate their potential in modifying flour for industrial use. At the same time we encountered an interesting relationship. We were working with a series of air-classified flour fractions supplied by our Engineering Development Laboratory. These contained protein ranging from 2.5 to 23 percent. The samples were treated with pepsin and crystalline α-amylase. The aim was to modify both the protein and the carbohydrate. To each flour fraction was added the same amount of additional bacterial amylase. With increase of the protein to 9, 13, and 23 percent, there was a progressive decrease in the length of time required to reach the desired viscosity. We explained this on the assumption that the higher protein concentrations carried more native enzyme which would augment the added enzyme and thus cause the reaction to proceed faster.

In another experiment with the same flour samples, pepsin was used as before to solubilize the gluten, but the crystalline α-amylase was varied in amount so that the final viscosity of each sample was in the neighborhood of 1000-5000 centipoises. The enzyme-treated products were then tested as surface-sizing materials.

Flours represented in Figure 1 had zero protein (starch), 7 percent protein already mentioned, 13 percent and 23 percent protein. Four TAPPI standard tests were applied to paper treated with these to test the quality of the products as paper sizes.

Tear factor: Paper strip cut and then pulled apart.

Breaking length: Measure of tensile strength--in terms of length in meters of paper strip that will support its own weight.

Porosity: Measure of permeability to air that is related to feel of the paper, printability, etc.

Burst: Mullen burst test.

The Figure shows that, as the protein level was increased, the sizing test values were mostly decreased. It is possible that different, as yet untried, treatments would improve the performance of the flour samples as surface-sizing material.

Our observations and others made by workers in the Engineering Laboratory led us to evaluate more specifically the effect of the native or indigenous enzymes in our flour containing 7 percent protein. Twenty percent wheat flour slurries were used; time of reaction, temperature and pH were studied. The optimum reaction time was 2-4 hours when the temperature was 60-65° C. and the pH was held in the effective range of 5.0 to 6.0. Flour modified in this manner was good surface-sizing material.

We have done altogether a considerable number of paper sizing experiments with enzyme-modified flours, and I would like to present a summary of the results obtained on them and on comparison materials.

In Table 3, note three controls: unsized paper, paper sized with a

Table 3.--Tub size values: modified wheat flour

Size	Treatment	Viscosity	Burst	Breaking length (dry)	Tear factor	Porosity
		cp.	g./cm.^{2} / g./m.^{2}	meters	g./g./m.^{2}	sec./100 cc.
None (KC base paper)			16.0	4350	89	40
Superfilm 40	None	4700	22.9	4990	69	47
Wheat starch	Amylase	5000	21.1	4710	70	55
Wheat flour	Pepsin-amylase	1780	18.9	4320	73	54
Wheat flour	Subtilisin-amylase	1400	17.7	4000	95	38
Wheat flour	Amylase	4520	20.4	4910	83	44
Wheat flour	Native enzyme	3000	20.7	5150	80	75

commercial hypochlorite-oxidized starch (Superfilm 40) and amylase-treated wheat starch. The 7 percent protein flour was used. Some of the treatments of wheat flour shown gave rather inferior results. But flour modified to a workable viscosity with its native amylase, or more rapidly with added bacterial amylase, gave strength values approximately equal to those obtained with the selected commercial sizing material. However, continuous runs on industrial equipment will be necessary to demonstrate that the product is satisfactory in all respects for commercial use.

Reducing sugars produced in the modification of flour with its own amylase were higher than desirable. It appeared that the production of excessive reducing sugar was avoided in the case of the bacterial amylase preparations by the high temperature used which would inactivate the β-amylase in the flour. We, therefore, investigated inhibition of β-amylase activity with graded amounts of ascorbic acid.

In Table 4 we see especially what happened to reducing sugars,

Table 4.--Enzyme modification of flour inhibition of β-amylase by ascorbic acid

	Ascorbic acid concentration, g./60 g. flour			
	5.0	2.5	0.25	none
% Total dispersion	73.5	66.2	75.3	78.4
% Reducing sugars	4.9	8.0	20.6	21.7
% Carbohydrate dispersed	67.8	70.3	80.6	93.7
% Non-dialyzable carbohydrate	87.9	87.3	46.8	40.9
% Protein dispersed	30.0	31.7	36.8	40.8
Burst	22.2	20.8	20.6	20.4
Breaking length (dry)	5260	5110	4720	4550
Tear factor	72	70	71	81
Porosity	53	65	47	60

carbohydrate dispersed, non-dialyzable carbohydrate and paper sized with the products. As shown, the incorporation of ascorbic acid markedly lowered the amount of reducing sugar produced and at the same time gave a 10 to 15 percent increase in strength measured by burst and by breaking length. This improvement was presumably due to the increase in dispersible non-dialyzable carbohydrate.

In view of the success that we had encountered in modifying the viscosity of unbleached flour with its own enzymes, we undertook comparable experiments with bleached flour. A sample of bleached flour made from hard red winter wheat was incubated 4 hours at 62°, then gelled 45 minutes at 95°. The product had poor dispersibility and viscosity too high for paper coating operation. Bleaching obviously interfered with the native amylolytic enzyme

so that the bleached flour could not be self-converted to a sizing material. We need yet to compare this experiment with a similar one on unbleached flour from the same source, but we assume for the moment that such an unbleached flour, would, like the others tested, give a good paper size.

In recapitulation, I should perhaps reiterate that the adaptation of wheat flour for use as a paper sizing or coating adhesive involves the two main constituents--starch and gluten. You have noticed that I have reported more results on the modification of the starch than on the modification of the protein present. This is a reflection, of course, on the greater difficulty of obtaining a favorable contribution in wanted properties from the protein. We were able to show that a proteolytic enzyme such as pepsin could be used to solubilize the gluten while at the same time keeping the bulk of the protein of sufficient molecular size that it did not dialyze. But the modification seemed to have little effect on sizing or adhesive properties. Other chemical and enzymatic approaches need to be tried. We have found that a treatment of wheat flour with alkali followed by a treatment with α-amylase gave a product that was a reasonably good size and also for the first time a good coating adhesive. Such results are encouraging.

Our main progress made in this investigation thus far has been to show in laboratory scale applications that a 7 percent protein flour can be enzymatically converted to a paper-sizing product comparable to commercial surface-sizing agents.

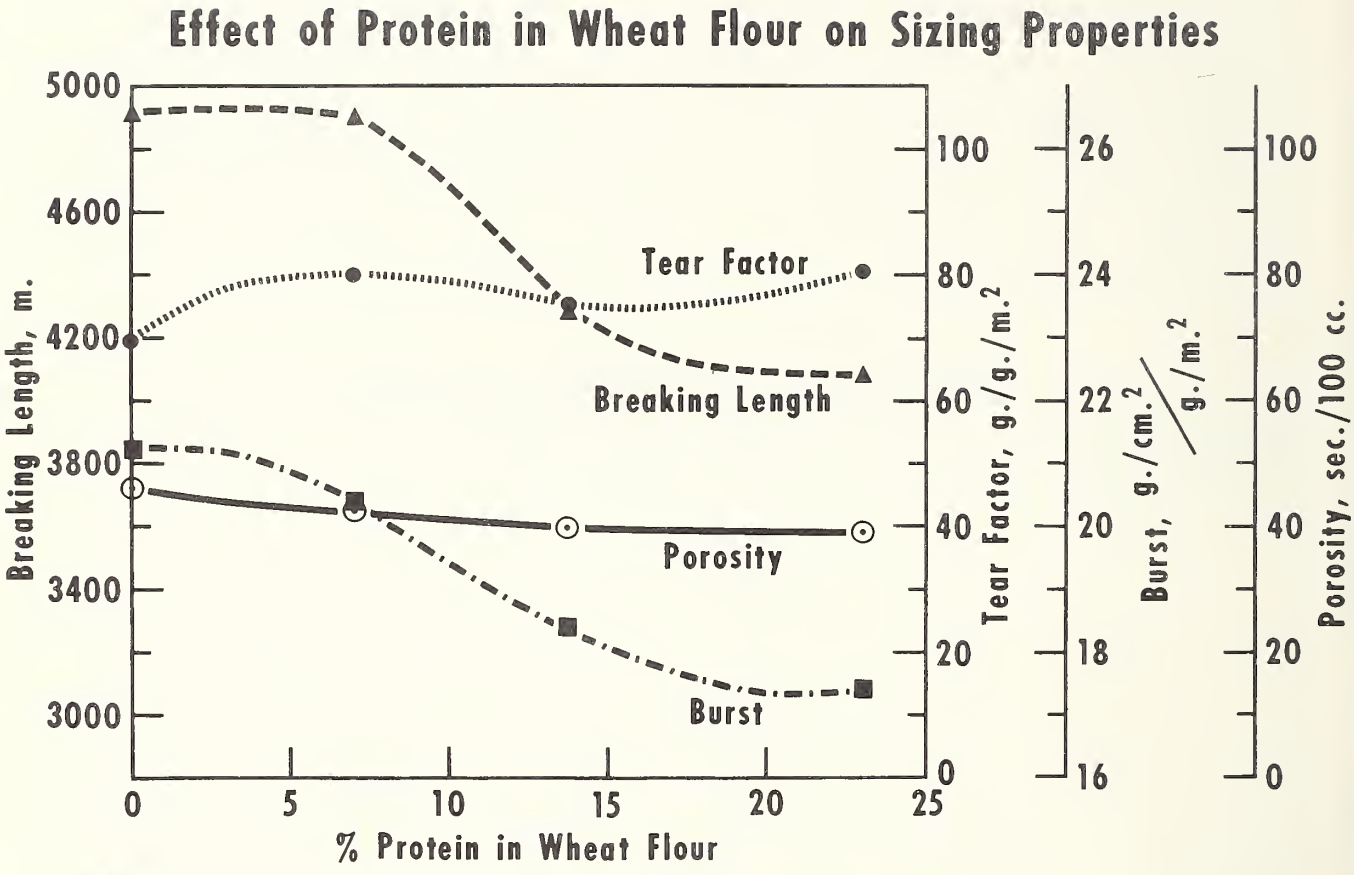
Effect of Protein in Wheat Flour on Sizing Properties
Breaking Length, m.
5000
4600
4200
3800
3400
3000
Tear Factor
Breaking Length
Porosity
Burst
0
5
10
15
20
25
% Protein in Wheat Flour
Tear Factor, g./g./m.2
100
80
60
40
20
0
Burst, g./cm.2 / g./m.2
26
24
22
20
18
16
Porosity, sec./100 cc.
100
80
60
40
20
0

Fig. 1

WHAT INDUSTRY CAN CONTRIBUTE TO THE INDUSTRIAL USE OF WHEAT

R. E. Chaddock
Hercules Powder Company, Inc., Wilmington, Delaware

Hercules became acutely interested in the industrial use of wheat about 7 years ago through the purchase of Huron Milling Company at Harbor Beach, Michigan. At the time of our purchase, the plant was processing wheat flour into gluten and starch. The starch was being sold into a number of industries, and the gluten was being hydrolyzed to make monosodium glutamate.

In the last several years, as a result of research and development activities, the operations at Harbor Beach have changed considerably as shown in Figure 1.

"Second clears" flour arrives in bulk cars at the plant and is stored in large outside silos.

From the silo, flour is fed to a mixer where water is added to form a dough. This is pumped into washers where the gluten is separated from the raw starch.

Several years ago, the development of new fermentation processes for making monosodium glutamate made it unprofitable to process gluten for this use. The gluten is now dried, ground, and sold as vital gluten.

The raw starch slurry is screened to remove the bran and centrifuged into different grades of starch. After further mild chemical treatment, the starch is either roll dried or spray dried, depending upon the end use. Wheat starch is used in the food industry, as laundry starches, in the paper industry, in oil well drilling, and in a number of other miscellaneous uses. Wheat starch is also used as the raw material for various derivatives which we manufacture under the tradename Ceron.

In addition, we convert wet starch by hydrolysis into glucose which is used as the raw material for the Hercules fermentation process to produce monosodium glutamate. This represents a complete turn around in our operation, from gluten to starch as the raw material for monosodium glutamate.

In the United States, in addition to Hercules, there are several other major companies who are known to wash wheat flour. It is our guess that somewhere in the neighborhood of about 20 million pounds of wheat flour is consumed monthly in flour washing operations.

Figure 2 shows the use of wheat starch and corn starch in the food industry. The figures are our best estimates based on miscellaneous published

reports and information reported by customers. As you can see, more than 10 times as much corn starch is used in food uses as wheat starch.

Figure 3 shows the industrial uses of corn starch and wheat starch. Here, the amount of corn starch is more than 20 times greater than the amount wheat starch. Although I would not place too much reliance upon the accuracy of the individual figures for these uses of wheat and corn starch. I believe that the overall total is correct.

The only areas where appreciable volumes of wheat starch are sold, as compared to corn starch, are to commercial laundries, in prepared food mixes, to the baking industry, and for miscellaneous foods and adhesives. In these uses, wheat starch can command a higher price than corn starch for it has certain desirable end-use properties not found in corn starch.

However, the total volume of these uses is small and in the major sales areas, wheat starch must compete with corn starch on an equal price basis.

Since there are two products produced from the washing of wheat flour--starch and gluten--the practical limitation as to the amount of wheat starch produced depends upon the markets for gluten. Gluten markets are limited almost entirely to the bakery and cereal industries. This use for gluten has developed over the last 3 to 5 years and is growing steadily. If wheat starch could be upgraded in price and properties, the gluten market might be expanded by lower prices.

Why is it that the industrial utilization of corn is such a large industry, whereas the industrial utilization of wheat is so small? The basic properties of wheat starch and corn starch are not too different; therefore, there must be some other factor influencing the lack of growth of the industrial use of wheat.

Figure 4 shows the costs of wheat and corn starch, assuming that the starch carries all the raw material costs. Our calculations show that with a corn price of around $1.20 per bushel, the raw material cost for corn starch is $3.90 per hundredweight. To begin to approach this figure for wheat starch, the price of clear flour would have to be in the neighborhood of $2.50 per hundredweight.

To greatly increase the industrial use of wheat, it is necessary that wheat flour be priced at a level so that wheat starch can compete economically with corn starch. If this should occur, our consumption of wheat flour would increase many fold. In spite of this, what is being done by industry to increase the industrial use of wheat?

Over the past 5 years, we have had a number of chemists working on the technology of wheat starch and starch derivatives. We hoped to discover unique products which could command sales prices high enough to overcome the economic disadvantages of raw wheat starch. We have several products undergoing market development now which are chemically modified derivatives of wheat starch.

GPO 809-570-3

As stated earlier, Hercules research discovered a new microorganism for the production of monosodium glutamate, and after lengthy process studies, a plant was designed and constructed at Harbor Beach, Michigan, to produce monosodium glutamate by fermentation methods. The Hercules process is based on using hydrolyzed starch and, in our particular case, we hydrolyze wheat starch. The hydrolyzed starch is the basic material upon which the microorganism feeds and grows, and in turn produces glutamic acid. The glutamic acid is recovered and converted to monosodium glutamate using existing facilities at Harbor Beach.

We hope to use a considerable amount of wheat starch to produce monosodium glutamate; however, again, this is not a unique use for wheat starch. Corn starch could be just as easily converted to the hydrolyzate. Since it is our desire to upgrade wheat starch, we would rather use our own wheat starch than purchase corn starch.

In the case of gluten, we have spent many research dollars in attempting to find new uses for gluten. During the last few years, we have developed a firm business based on the production of vital wheat gluten.

Much research effort was devoted to separating gluten into its components gliadin and glutenin and attempting to develop markets for these two products. In addition, we have hydrolyzed gluten into its various amino acids and developed separation processes for isolating the amino acids. However, at the present time, the markets for these amino acids are not large enough to justify building an amino acid plant.

Now, what can industry contribute to the industrial use of wheat?

First, industry can contribute its processing knowledge of separating wheat flour into its major components, gluten and starch. We are constantly working to find better methods of handling wheat flour and trying to improve our operating techniques to make these methods more economical.

Second, industry can contribute its marketing and applications know-how to increase the sale of the products available from wheat. An example of this is the recent introduction by our company of a product we call Hercules Micro-Starch. Micro-Starch is a fine, white, free-flowing starch made from wheat flour by a special Hercules classification process. This was developed because of a need uncovered in the market place by our people for a wheat starch in the 2 to 10 micron granule range.

Third, industry can contribute its vast and specialized knowledge of chemical processing techniques to upgrade the products available from wheat. Once a new product has been discovered and it is determined that a market does exist, our engineers can design an efficient plant which will produce a profitable product.

Fourth, a very important contribution that industry can make is to turn loose its research chemists so that they may develop new products from wheat. However, it is not enough just to develop new products from wheat--it is necessary that these products satisfy some need in the market place and

are sold at a price at which industry can make a profit. In order to support costly research, applications, and marketing efforts, industry must make a satisfactory profit from the industrial use of wheat.

However, all of these contributions can never take place if we continue to be faced with shortages and artificially high prices for whatever wheat product we buy.

The use of wheat clears as an industrial raw material is unprofitable because of the government export programs. In addition, also due to these programs, we cannot even buy the quantity of clears which we need to profitably operate our plant.

The total loss at this moment of industrial outlets for wheat clears would be catastrophic for the future development of wheat as an industrial raw material. The possibility of a major research breakthrough on the use of wheat by companies such as Hercules would cease to exist.

FLOUR PROCESSING

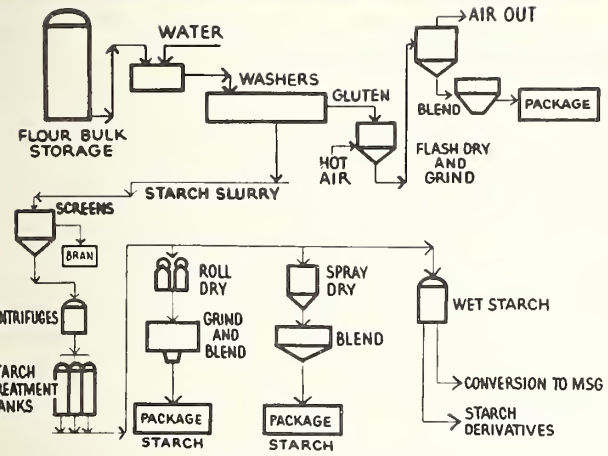

Fig. 1

STARCH

FOOD USAGE

LBS. PER MONTH

	CORN STARCH	WHEAT STARCH
BAKING INDUSTRY	3,330,000	225,000
BAKING POWDER	1,900,000	NEGLIGIBLE
BREWING INDUSTRY	9,420,000	"
CANNERS & PACKERS	2,300,000	"
CHEMICALS, DRUGS, PHARMACEUTICALS	2,000,000	"
CONFECTIONERY	4,160,000	"
MIXES, PREPARED	2,930,000	975,000
MISC. - FOOD	7,460,000	1,500,000
TOTAL	33,500,000	2,700,000

TOTAL

CORN STARCH 33.5 MIL. LBS.
WHEAT STARCH 2.7 MIL. LBS.

Fig. 2

STARCH

INDUSTRIAL USAGE

LBS. PER MONTH

	CORN STARCH	WHEAT STARCH
LDING MATERIALS	4,400,000	100,000
LERS & REPACKERS	2,200,000	NEGLIGIBLE
BBERS	1,620,000	"
UNDRIES	1,600,000	1,100,000
ER, LAMINATING & CORRUGATING	22,800,000	2,000,000
ER, OTHER	62,000,000	
TE, ADHESIVES, DEXTRINS	1,250,000	850,000
XTILES	24,000,000	900,000
SC. - INDUSTRIAL	3,960,000	NEGLIGIBLE
TOTAL	123,830,000	5,100,000

TAL

CORN STARCH 123.8 MIL. LBS.
WHEAT STARCH 5.1 MIL. LBS.

Fig. 3

STARCH

RAW MATERIAL COSTS

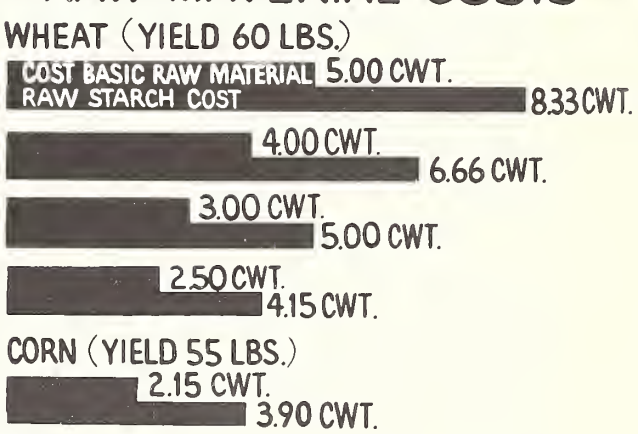

Fig. 4

REVIEW OF PUBLISHED INFORMATION ON RADIONUCLIDES IN WHEAT AND OTHER AGRICULTURAL PRODUCTS

V. F. Pfeifer, Principal Chemical Engineer
Engineering and Development Laboratory, Northern Utilization Research and Development Division, USDA, Peoria, Illinois

Work is now beginning at the Northern Division on a new project to compare and develop methods of processing wheat and milled products to reduce the content of the radionuclides strontium 90 and cesium 137 should this become necessary in event of nuclear emergency.

Present levels of radioactive contamination from fallout in wheat and milled products are considered so low that the U.S. Federal Radiation Council concludes that the health risks from present levels of fallout due to testing through 1962 are too small to justify measures to limit the intake by modifying the diet, or to alter the normal distribution and use of food, or to treat foods to reduce their level of radionuclides (1). The present weapon testing ban will help eventually to drop levels to lower values. However, in case of an emergency in which there would be heavy and dangerous contamination of wheat by radioactive fallout, we must have information available to permit us to decontaminate the wheat or milled products to levels suitable for our consumption in foods and feeds. This work must be done now, and the information made available to producers, millers, and food and feed processors.

With the explosion of the first nuclear devices in 1945, we began introducing man-made radioactive contamination into our atmosphere. Up until 1952 the amounts produced were minor, but since that time the production of these man-made radioactive nuclides has increased considerably.

Around 200 different radionuclides are produced or are dispersed in unfissioned form during a nuclear detonation (2, 3). Only a few of these are of importance in foods. These have relatively long life, are energetic emitters of radiation, are readily absorbed in the gastrointestinal tract, and are produced in appreciable percentages of the total fission yield.

The important radioactive elements formed by the fission yield of a nuclear explosion are shown in Table 1 (4, 5). Iodine 131, a gamma ray emitter, has a half-life of only about 8 days, but is important because it concentrates in the thyroid gland. Barium 140, a beta and gamma ray emitter with a half-life of only 13 days, and strontium 89, a beta ray emitter with a half-life of 53 days, tend to deposit preferentially in the bones, where they remain until their radioactivity disappears. Cesium 137, which emits both gamma and beta rays, has a half-life of 30 years, and behaves somewhat like potassium in our metabolism. It distributes itself throughout the entire soft tissue of the body. Strontium 90, a beta ray emitter, has chemical properties similar to calcium, and deposits in the bone along with it. Because of its deposition in bone and its long radioactive half-life, 28 years, it is the most important fallout radionuclide.

TABLE 1.--Fallout radionuclides of importance in foods

Radionuclide	Half-life	Radiation
Iodine 131	8 Days	Gamma
Barium 140	13 "	Beta, gamma
Strontium 89	53 "	Beta
Cesium 137	30 Years	Beta, gamma
Strontium 90	28 "	Beta

Iodine 131, barium 140, and strontium 89 have such short half lives that they can be ignored in our considerations of wheat and wheat products. By the time the wheat is milled, these compounds will have disappeared or diminished considerably in concentration due to radioactive decay. However, strontium 90 and cesium 137, with their long half lives, are potentially dangerous. Of these, cesium 137 is considered less dangerous, at least to the individual, because it has a short life in our bodies--half of the cesium 137 is eliminated in a few months (6) due to rapid replacement of body cells in our tissues. Strontium 90 is thus the most important radionuclide; with its radioactive half-life of 28 years and its body retention half-life of about 50 years it has an effective half life in our bodies of about 18 years.

Weapons with energy releases of 1 megaton or more discharge their fission products to the stratosphere (6), which is above the 30,000 to 55,000 foot upper level of the troposphere. In the stratosphere the fission products become quite widely dispersed throughout the entire world, and eventually return to the earth over about a 5-year period. Most of the fallout is to the hemisphere from which the bomb is exploded. Much of the northern hemisphere fallout is in the North Temperate Latitude that encompasses the United States. This stratospheric fallout is responsible for most of the radioactive contamination of our foods, soil, and water. The radioactive particles are present in the submicron range, as evidenced by their 5- to 10-year stratospheric storage time. The activity is deposited by rains, and is substantially in water-soluble form. In fact, over limited geographical areas, a linear correlation has been found between radioactive fallout in soil and total rainfall (7).

Rain deposits fallout both in the foliage of the plants and in the soil. It is presently believed that most of the radioactivity in plants is by fallout to plant foliage rather than by root absorption from the soil (4). Strontium 90 is regarded to be relatively immobile and to be redistributed to only a small extent after foliar absorption (8, 9). Cesium 137, however, is considered much more mobile, and readily translocated from the foliage to developing organs and roots.

In wheat, the absorption of radioactive material is quite dependent upon the state of development of the plant at the time of fallout, and the rainfall during development of the heads. If rainfall is slight during and after head growth, the wheat will contain much less radioactive contamination than if the rainfall occurs during head formation. Workers in this field

(3, 10, 11) have estimated that about 80 to 90 percent of the strontium 90 in wheat is by foliar deposition of fallout, and only about 10 to 20 percent by root absorption from the soil.

The units of measurement for radionuclides are shown in Table 2. The

TABLE 2.--Measurement and production of radionuclides

Unit	Symbol	Value
Megacurie	Mc	10^6 curies
Curie	c	1 curie
Millicurie	mc	10^{-3} "
Microcurie	uc	10^{-6} "
Nanocurie (millimicrocurie)	nc (muc)	10^{-9} "
Picocurie (micromicrocurie)	pc (uuc)	10^{-12} "

1 Curie = 2.2×10^{12} dpm
1 Picocurie = 2.2 dpm
1 Megaton of fission energy produces 100,000 curies of Sr 90
1 " " " " " 160,000 " " Cs 137
World production of Sr 90 9 Mc 1958; 19 Mc 1963
" " " Cs 137 14 " " ; 31 " "

curie (c), the unit of measurement, is the amount of a given radionuclide that undergoes 2.2×10^{12} disintegrations per minute. The picocurie, the unit popularly used in discussing radioactive contaminants in wheat and wheat products, is the amount of a radionuclide that undergoes 2.2 disintegrations per minute.

One megaton of fission energy produces about 100,000 curies (0.10 Mc) of strontium 90 and about 160,000 curies (0.16 Mc) of cesium 137 (6). In late 1958 the world production of strontium 90 was estimated to be about 9 Mc; in 1963 this had risen to about 19 Mc (1). For cesium 137, the corresponding figures are 14 Mc in 1958, and 31 Mc in 1963.

The Federal Radiation Council, which was established in 1959 to advise the President on radiation protection policies, has set a series of ranges for normal peacetime operations (12). These ranges, shown in Table 3 for strontium 90, have been established as a balance of the benefits to be derived from the controlled use of radiation and atomic energy against the risk of radiation exposure. The ranges are based on the "Radiation Protection Guide," which is a definite radiation dose not to be exceeded without careful considerations of the reasons for doing so. The ranges are designed so that in Range 1 no appreciable number of individuals will reach the dosage of the RPG. In Range 2, average exposures would not exceed the RPG, but for Range 3, the RPG would be exceeded if intake continued for a sufficient time. Range 2 should thus be considered in the use of wheat and wheat products as foods.

TABLE 3.--Ranges for intake of Sr 90 established by Federal Radiation Commission

Range	Daily intake pc/day	Action recommended
1	0-20	Periodic confirmatory surveillance
2	20-200	Quantitative surveillance, routine control
3	200-2000	Evaluation and application of additional control measures as necessary

For normal peacetime operations.
To be applied to the average of suitable samples of an exposed population group.

Table 4 lists the maximum permissible concentrations and body burdens

TABLE 4.--ICRP recommendations for intake of Sr 90 and Cs 137 for occupational exposure

	Sr 90	Cs 137
Maximum permissible burden	2×10^6 pc (bone)	30×10^6 pc (body)
" " concentration-water	1 pc/cc	200 pc/cc
" " " -air	0.1 pc/liter	20 pc/liter
Total per day, occupational	2,100 pc	420,000 pc
" " " , general population	70	4,200

Average water consumption per day -- 2200 cc.
Average volume of air breathed per day -- 20,000 liters

for occupational exposure by radiation workers as recommended by the International Commission on Radiological Protection (13). They are based on 168 hours per week exposure, and assume 50 years exposure period at constant level. These values may be applied with caution to foods. For the average general population, the ICRP first advised dividing by a factor of 10, later by 30, for a total intake per day of 70 pc of strontium 90, 14,000 pc of cesium 137. Later a factor of 100 was recommended for cesium 137 because of possible genetic effects, bringing this down to about 4,200 pc per day. The value of 70 pc per day for strontium 90 is about one-third of the top Range 2 (200 pc per day) of the FRC.

The Health and Safety Lab. of the AES has carried out many measurements of strontium 90 in wheats grown in the U.S. over the past 5 years, in order to provide data on movement of strontium 90 through the food chain to the bones of human beings. Some of their data on wheats for 1958-1962 are given in Table 5 (10,14,15), together with cumulative fission yield from nuclear testing during this period (1). We see that the average strontium 90 content of

TABLE 5.--Nuclear weapons testing and Sr 90 in wheat

Year	Sr 90 in wheat pc/Kg	Total fission yield megatons
1956	..	52
1958	62	92
1959	53	92
1960	28	92
1961	25	117
1962	83	193

U.S. Wheat Data -- J. Rivera (10,14,15).
Nuclear weapons testing data -- Federal Radiation Council (1).

U.S. wheat dropped from 1958 to 1961, then started to increase.

The test moratorium of 1959 through the first half of 1961 is clearly reflected in the steady reduction of strontium 90 in wheat during this period. In the fall of 1961 Russia resumed testing, and 1962 wheat increased in strontium 90 content as a result. The combined effect of 1961 and 1962 testing is expected to raise the 1963 wheat to higher levels.

We have seen that most of the fallout radionuclides adhere to the foliage and outer seed coverings. Small amounts are probably translocated, but the bulk of it stays with the outer or feed layers of the wheat kernel. The HASL has carried out studies on the strontium 90 content of milled products from various wheats. Table 6 shows data by Rivera covering the

TABLE 6.--Sr 90 in U.S. wheat and milled products, pc/Kg.

Material	1958	1959	1960	1961	1962	% of Sr 90 in original wheat
Wheat	62	53	28	34	90	100
Patent flour (58%)	12	9	4	6	17	9
Clear " (14%)	28	17	9	..	57	5
Germ and shorts (14%)	133	143	66	88	370	35
Bran (14%)	231	163	107	..	486	51

Data of J. Rivera (14,15).

1958-1960 U.S. wheats (15) and Kansas wheat only for 1961 and 1962 (14). Here we can clearly see that milling is effective in diverting much of the radioactive contamination of the wheat to the feed fractions, so that the flour is quite low in strontium 90. In these tests the patent flour amounted to about 58 percent of the wheat, and retained on the average of about 9 percent of the strontium 90 present in the original wheat. The clears, amounting to about

14 percent of the wheat, retained about 5 percent of the strontium 90. The shorts and germ, amounting to about 14 percent of the wheat, retained about 35 percent of the strontium 90; and the bran, amounting to about 14 percent of the wheat, retained about 51 percent of the strontium 90. We thus see that by milling the wheat to flour and diverting the bran and shorts to feed uses, we effectively reduce the strontium 90 in the food fraction remaining to about 14 percent of that in the starting wheat.

Results of surveys of human diets in the U.S. and abroad, to indicate the contributions of strontium 90 and cesium 137 by various foods, are shown in Table 7 (4,16,17,18). Here it can be seen that milk and dairy products

TABLE 7.--Distribution of Sr 90 and Cs 137 in human diet

	Sr 90, % of total			Cs 137,
Item of diet	Teen-age 1961-1962(16)	U.S. tri-city 1960-1962(17)	U.K. 1961(18)	% of total U.S. diet (4)
Milk and milk products	59	41	51	61
Vegetables	12	20	15	4
Meat, seafood, eggs	6	4	5	24
Cereals, baked products	13	22	15	7
Fruits and others	7	10	4	4
Water and beverages	3	3	10	..

are the largest contributors of strontium 90, while cereal products and vegetables are next and of somewhat equal magnitude. Cereal products account for about 20 percent of the strontium 90 intake as our diets are at present, and this is the portion in which producers, millers, processors, and research workers have a particular concern. Considering cesium 137, over one-half of the radionuclide is from milk and dairy products, about one-fourth is from meat, seafood, and eggs, and only small amounts are from vegetables, cereal products, fruits, and other sources.

Table 8 shows how the intakes of strontium 90 and cesium 137 are increasing steadily due to 1961 and 1962 weapons testing (19,20,21). The maximum presently established by the FRC for the top of Range 2 is 200 pc of strontium 90 per day (Table 3), and the maximum permissible intake based on ICRP recommendations for general population is about 4,200 pc per day for cesium 137 (Table 4). The levels shown here are well below those of the recommended limits, but the results show how nuclear testing can increase the radionuclide content of our foods.

In case of heavy contamination by radioactive fallout, wheat offers one of our safest sources of raw materials for foods, although some mineral supplementation, with stable calcium especially, might be required. But we must have available all possible information for decontaminating wheat, bran, and flour to make them as safe as possible. Presence of fallout radionuclides in wheat and wheat products presents an obligation to wheat

TABLE 8.--Daily intake of Sr 90 and Cs 137 in teen-age total diet

Date	Sr 90 pc/day	Cs 137 pc/day
November 1959	22	..
January 1961	13	..
May 1961	11	37
January 1962	15	38
March 1962	18	59
June 1962	30	132
March 1963	32	161

Data of Michelson (19,20,21)

producers, wheat millers, food and feed processors, to take whatever measures they can to eliminate or reduce the contamination of their respective products.

In the case of wheat producers, there are a few possibilities. For example, it is possible to grow varieties of wheat that take up lower amounts of radioactive strontium from the soil. Table 9 shows results of greenhouse

TABLE 9.--Effect of wheat variety on Sr 89 uptake from soil

/Greenhouse studies/

Variety	DPS/g. of dry wheat		
	Grain	stems	Leaves
Kentena 52	106	1026	3815
Canus	91	398	2370
Progress	81	518	1695
Cadet	76	290	2181
Carleeds	49	799	2484
Great Northern	41	347	1918
Average	74	563	2410

Data of Rasmusson, Smith, and Myers (22)

tests (22) in which different wheat varieties were grown in soil containing the same level of strontium 89, used because of its short half-life. The strontium 89 content of the different wheats varied from 41 to 106 DPS/g. in the grain; from 290 to 1,026 in the stems; and from 1,695 to 3,815 in the leaves. Evidently the genes affect both absorption and transport of the strontium 89. Presumably strontium 90 would behave in a similar manner. Other agronomic factors reported to affect the pickup of radioactive fallout include soil type, method of cultivation, fertility level, and content of organic materials (2,23).

By the ordinary milling process the strontium 90 content of the flour can be reduced to from 10 to 15 percent of that originally present in the starting wheat. It is hoped that additional studies will make it possible to reduce this still further. The other 85 to 90 percent of the strontium 90 is in the fractions now fed to animals. If fed to meat-producing animals most of the strontium 90 will be retained in the animal skeleton, and will not grossly contaminate the meat.

Work has just begun at the Northern Laboratory on this project. Presently wheats of the 1963 crop from various parts of the U.S. are being examined, and the distribution of strontium 90 in the milling products from these will be determined. With one wheat from the Midwest the various parts of the wheat plant itself have been separated and the separated wheat kernels have been milled to produce patent flour, clear flour, shorts, and bran.

Investigations of the effects of various wet and dry cleaning procedures applied to these wheats are planned, and special treatments to reduce the radionuclide content of the flour and feed products as much as possible will be developed. Both the feed and the endosperm portions will be considered, and it is hoped that each will be improved. A variety of washing procedures with various additives will be employed, as well as any physical separation methods that appear applicable.

Wet and dry cleaning equipment of conventional design will be acquired for use in the work. Analytical equipment will include low-level beta and gamma counting equipment of the manual type, and the necessary furnaces and lab equipment to permit radiochemical separations and the estimation of the content of radionuclides in the wheats and milling products.

With the present ban on nuclear testing, levels of fallout radionuclides in wheat and milled products will drop to lower values. Our soil has been contaminated somewhat and will remain substantially unchanged for some years. Wind borne dust and root absorption will thus continue to be factors for sometime. Removal of strontium 90 in wheat at its present level of contamination is considered unnecessary and impractical (1). Processes for removing strontium 90 from milk on a pilot-plant scale, have been reported (24,25,26), and are now being evaluated commercially for possible use in an emergency. Similar processes for the decontamination of wheat and milled products in case of an emergency are needed. With attention to this problem by producers, millers, food and feed processors, and research workers, it is hoped that the high nutritional and biological qualities of our wheat and milled products will be maintained in any situation that might arise.

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QUALITY EVALUATION OF EARLY-GENERATION WHEAT PROGENIES

Karl F. Finney, Chemist
Hard Winter Wheat Quality Laboratory, Crops Research Division,
Agricultural Research Service, USDA, Manhattan, Kansas

Introduction

It is a privilege to talk with you about suitable methods of evaluating the milling and baking quality of relatively large numbers of early-generation wheat progenies available in small quantities (only 100 to 200 grams).

Breeding hard wheats that will lay down 1 to 2 percent more gluten protein in the grain, that will ripen 2 to 3 days earlier than present varieties, that are resistant to rusts, hessian fly, or mosaic viruses, or that will withstand the usual effects of adverse weather requires that hundreds and sometimes thousands of new progenies be studied in the field each year. To carry out effectively and efficiently the agronomic phases of the breeding program and to assure that good-quality selections be preserved, it is often imperative that 100- to 200-gram samples of hundreds of new, early-generation progenies be screened for milling and baking quality in addition to the several hundred 4- to 10-pound samples of more advanced varieties that are tested each year on a regional basis in the Hard Winter Wheat Quality Laboratory. For several reasons it usually is not feasible to bake the flours from the small samples to be screened, but instead is highly desirable to be able to apply two or three relatively simple and less time-consuming physical and chemical tests that (1) will satisfactorily measure one or more of the important baking properties and (2) can be used to predict other important baking properties constituting quality.

Meaning of Quality

Physical and chemical differences are strikingly great between different lots and varieties of wheat. These differences have far-reaching effects and become the basis for what loosely is referred to as quality whether the problem relates to testing and evaluating, cereal chemistry research, processing, or economics. Actual quality of a wheat is the summation effect of soil, climate, and seed stock on the wheat plant and the kernel components, particularly gluten protein.

Before the quality of several pounds or only a few ounces of wheat can be evaluated, quality must be defined and then measured by suitable methods. Hard wheat quality is defined (Table 1) in terms of specific milling and baking properties that determine the suitability of a wheat for hard wheat milling and bread production.

TABLE 1.--Milling and baking properties that determine the suitability of a wheat for hard wheat milling and bread production

Properties evaluated	
Milling	Baking
Bolting	Flour protein
Hardness	Mixing requirement
Flour yield	Mixing tolerance
Flour ash	Oxidation requirement
Wheat protein	Dough handling
	Water absorption
	Loaf volume
	Crumb grain and color

Specifically, a hard winter wheat of good milling quality should have normal bolting or sifting properties and thereby should be neither unusually hard nor soft. A wheat that is too hard usually will require more power and more than the normal number of break and reduction operations. The flour therefrom usually will have a relatively high ash content. If a wheat is too soft, the mill flow will be altered as a result of an unusually high quantity of break flour. If the wheat, in addition, gives a normal yield of flour with a normal quantity of ash, almost invariably it will be suitable as a good milling hard wheat.

A flour of good quality for bread baking should have a high water absorption, a medium to medium-long mixing requirement, a small to medium oxidation requirement, satisfactory mixing tolerance and dough-handling properties, and good loaf-volume potentialities (considering protein content), and yield a loaf having good internal crumb grain and color.

Thus, quality of hard winter wheat cannot be expressed in terms of a single property, but depends on several milling, baking, and physical dough characteristics each important in the utilization of wheat.

Determination of Milling Properties

How can the important milling properties be determined satisfactorily on large numbers of 100- to 200-gram samples of early-generation progenies of wheat? There are no physical or chemical tests that satisfactorily predict milling quality except a micro experimental milling setup such as that illustrated in Figure 1, which shows prebreak rolls (P), a 3-break head (B) containing four break rolls, ro-tap sifter (S), and a 3-reduction head (R) containing four middlings or reduction rolls. A second ro-tap sifter used in conjunction with the reduction head is not shown. About five samples can be milled per hour.

The relatively simple flow of the prebreak, break, and middlings stock is given in Figure 2.

Figure 3 shows a closeup of the inside of the excellently engineered Brabender[1/] break head equivalent to three stands of break rolls. The corresponding reduction or middling head is identical except for the feed roll, roll spirals, and roll corrugations per inch.

When employing the above micro milling procedure and equipment, flour yields of 69 ± 6 percent and flour ashes of 0.40 ± 0.05 percent were obtained on several hundred 100- to 200-gram samples of wheat. Relative hardness or softness was observed and noted after breaking, reducing, and sifting operations. Undesirably hard or soft milling characteristics usually are reflected in lower flour yields, which in turn are evaluated relative to flour ash. Flour ash, however, usually is determined only on samples found to have desirable mixogram mixing properties.

Determination and Prediction of Baking Properties

Which relatively simple physical and chemical tests can be used to measure and predict important baking properties of flours milled from 100- to 200-gram samples of wheat? Let us start with flour moisture and protein contents and a mixogram test.

Mixing requirement and tolerance.--Mixing requirement and tolerance, two important baking properties of wheat flour, can be determined from the mixogram obtained on a mixograph (Figure 4). A mixogram can be run on 35 grams of flour and water equivalent to a suitable absorption. The instrument essentially is composed of two planetaries, each with two pins that revolve in a fanciful pattern about three stationary pins in the bowl.

Flour moisture content must be determined so that flours can be weighed and protein contents compared on a constant moisture basis. Flour moisture also is needed when calculating the water absorption for the mixogram.

Typical mixograms of flours that vary in mixing requirement and tolerance are illustrated in Figure 5. As the dough develops, the decrease in dough mobility and increase in the pull on the pins revolving through the dough are recorded on paper marked off by arcs at 1-minute intervals. The point of minimum mobility or maximum plasticity corresponds to mixing requirement in minutes. Thereafter, as mechanical degradation increases,

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1/ Mention of a trade product, equipment, or a commercial company in this publication does not imply its endorsement by the U. S. Department of Agriculture over similar products or companies not named.

dough mobility increases and the curve slopes downward and tails off to varying degrees depending on the rate of mechanical breakdown of the gluten protein mixing tolerance. About seven samples per hour can be run by a single operator.

Referring to the top, left mixogram in Figure 5, mixing requirement is less than 1 minute and mixing tolerance is very poor. Proceeding from left to right and top to bottom, it is particularly significant that mixing tolerance (slope of curve beyond the peak) increases as mixing time increases to 4 minutes. Thereafter, mixing tolerance remains constant with increasing mixing time. Although not shown in Figure 5, mixing requirements of 8 to 10 minutes are accompanied by mixing tolerances similar or identical to those shown for the two mixograms at the bottom of Figure 5. It is particularly noteworthy and significant that optimum mixing tolerance is reached when mixing requirement approaches 4 minutes. Thus, selecting new progenies of wheat with mixing requirements appreciably greater than about 4 minutes would not give increased mixing tolerance, but could and in many instances would increase production costs.

Protein content and mixogram characteristics.--The protein level of all flours involved in Figure 5 was about 13 percent. The effect of flour protein content on mixogram mixing time and tolerance is illustrated in Figure 6. Here, the mixing requirement of Pawnee wheat containing 7.5 percent flour protein is much longer and mixing tolerance is materially greater than for the usually encountered protein levels of 11 to 13 percent. Mixing time, in general, decreases as protein content increases to about 12 percent. Thereafter, mixing requirement remains approximately constant with increasing flour protein. For flours having low protein-starch ratios, more time or work is required to produce a continuous phase of protein.

The effect of protein content on curve characteristics of Quivira-Tenmarq x Marquillo-Oro, a long-mixing flour, is illustrated in Figure 7. Variations in curve characteristics with increasing protein content within a variety corroborate those in Figure 6. It is noteworthy that the height of the curve (Figures 6 and 7) increases with increasing protein content.

Of course, adverse weather or other unusual growing conditions usually would alter mixing requirement and other curve characteristics compared with those for the comparable and typical samples represented in Figures 6 and 7.

Oxidation requirement vs. flour protein and mixing requirement.--The general relation between oxidation requirement and flour protein content of Pawnee and Kaw, short and medium-long mixing varieties, respectively, is illustrated in Figure 8. Samples were harvested throughout the Southern and Central Great Plains in 1959, 1960, 1961, and 1962. The relatively large deviations about the imaginary regression lines are partly accounted for by the variation in mixing requirement within a variety and the interrelation of mixing time and oxidation requirement (Figure 9).

Thus, to minimize the effect of protein content variations, Figure 9 represents only groups of composite samples that had mean protein contents of 12 to 13 percent. Variety composites represent a wide range of quality characteristics and were made up of hard winter wheats harvested throughout the Great Plains in 1959 to 1962. Data in Figure 9 show that oxidation requirement decreases materially with increasing mixing time or requirement and reaches a minimum at about 5 minutes beyond which oxidation requirement is approximately constant. Thus oxidation requirement can be predicted from a knowledge of mixing requirement and flour protein content.

Although the mean flour protein of the sample groups varied from only 12 to 13 percent, the variation in protein within each group was about ± 1 percent of the mean. Accordingly, at least part of the deviation about the imaginary regression is attributable to a total protein content variation of about 11 to 14 percent.

Water absorption.--Working or "as received" flour absorption is a function of protein content, variety, flour moisture, and environment. Mixogram absorption is determined with the aid of the data illustrated in Figure 10, which show that water absorption (14% moisture basis) increases with increasing flour protein content within a variety (average of environments) and that the regression lines for different wheat varieties form a fan-shaped family of lines. The vertical distance between any two regression lines represents a genetic difference in water absorption. The regression line to be used for an unknown is estimated from the regression lines of the parents. If the parents are not known, the approximate mean regression line represented by Kharkof (Kk) or Tenmarq (Tm) would be employed. Thereafter, estimated absorption on a 14-percent moisture basis readily is adjusted for flour moisture content when necessary.

When a number of sister progenies are involved, the composite effect of variety and environment accurately can be determined after a few grams of each are composited to give 100 grams of flour for baking. During baking the suitability of the estimated absorption level can be ascertained. Thereafter the regression line representing the adjusted mean absorption of the sister progenies can be selected and applied to each sister. In any event, mixogram absorptions selected seldom are off far enough to prevent a reliable determination of mixing properties.

Short-mixing varieties have absorptions that may be either above or below the average. It is highly significant, however, that wheat varieties with medium-long mixing times almost invariably have above-average water absorptions. Thus water absorption can be predicted from mixing requirement, particularly when only the relatively strong progenies with medium-long times are selected.

Dough-handling properties and mixing requirement.--Data obtained during the past number of years indicate that flours with medium-long mixing requirements almost invariably will have good or even relatively strong dough-handling properties.

Loaf volume and mixing requirement.--Loaf volume at the 13-percent protein level (protein quality) increases as mixing time increases from 7/8 to about 3 minutes (Figure 11). Beyond 3 minutes, loaf volume at 13-percent protein is approximately constant with increasing mixing time. The lowest loaf volumes for mixing times greater than 3 minutes are considered to be barely satisfactory. Most of the others, however, are very good to excellent. Thus, mixing time or requirement obtained from the mixogram is a reliable index of loaf-volume potential or protein quality. Samples represented a wide range of wheat varieties harvested throughout the Southern and Central Great Plains in 1961 and 1962.

Loaf crumb grain and color.--A satisfactory loaf crumb grain almost invariably accompanies a good loaf volume potential, and a questionable or unsatisfactory loaf crumb color usually can be detected from the flour color at the time of milling.

Summary

A general evaluation of relative hardness, bolting properties, flour yield, and flour ash readily can be obtained on 100- to 200-gram samples of wheat. After obtaining flour moisture and protein contents, mixing requirement and tolerance can be determined from a mixogram. Oxidation and water absorption requirements, dough-handling properties, and loaf-volume potential can be predicted satisfactorily from mixing requirement.

The mixograph, in the author's opinion, is the most useful single instrument or test for predicting the breadmaking and physical dough properties of relatively large numbers of wheats available in small quantities (100 to 200 grams).

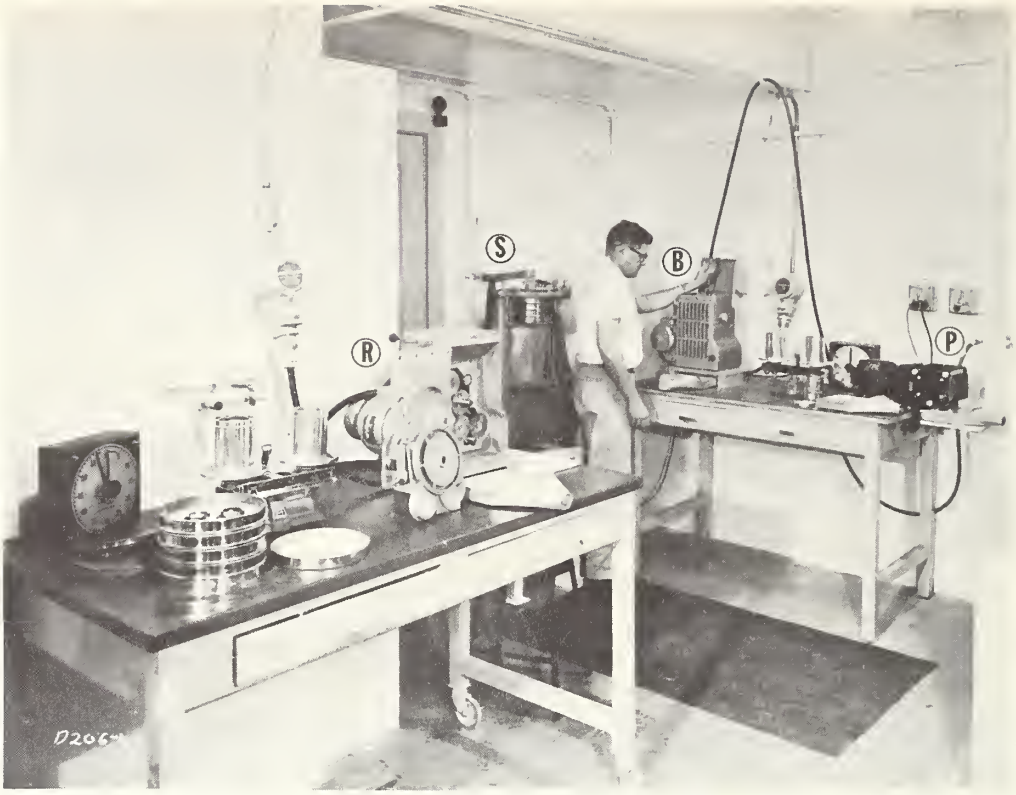


Fig. 1 Micro experimental mill composed of pre-break Tag rolls (P), Brabender 3-break milling head (B), ro-tap sifter (S), and Brabender 3-reduction milling head (R).

A second ro-tap sifter used with the reduction head is not shown.

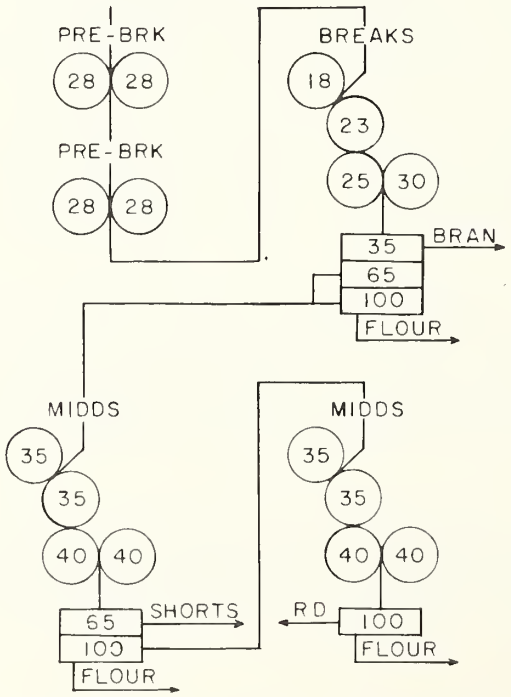


Fig. 2 Flow of the pre-break, break, and reduction or middlings stock, together with roll corrugations per inch and Tyler sieve openings per linear inch.

RD is an abbreviation for red dog.

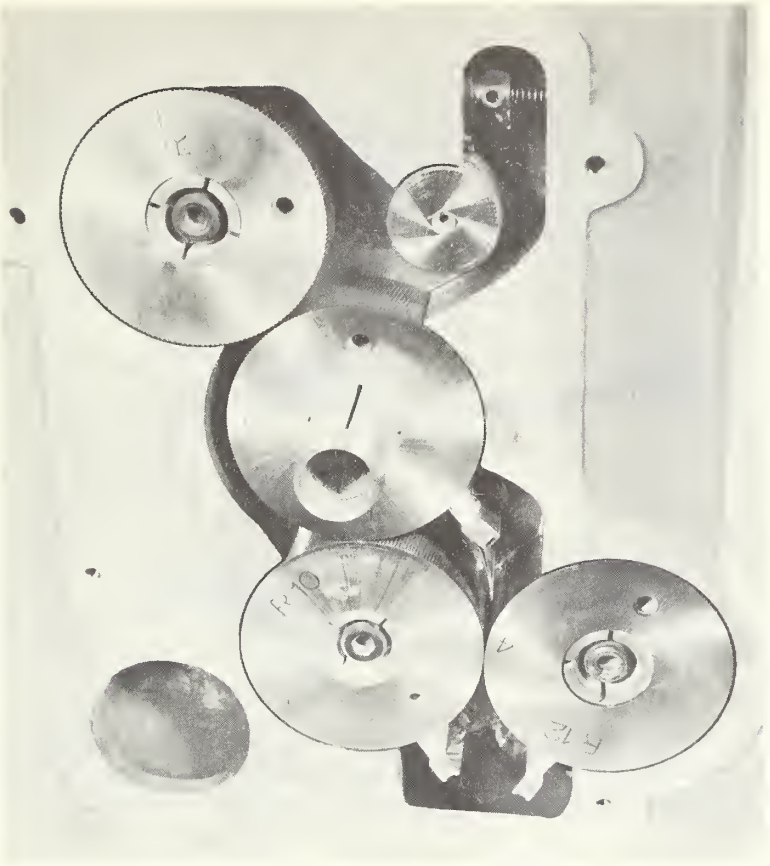


Fig. 3 Closeup of the interior of the Brabender 3-break milling head containing a feed roll, 4 break rolls, and roll-cleaning brushes. Break roll spirals are 1.5, 1.0, 1.0, and 0.5 inch per foot. Reduction or middlings head is identical except for the feed roll system, roll spirals (1.0, 0.5, 1.0, and 0.5), and roll corrugations per inch.

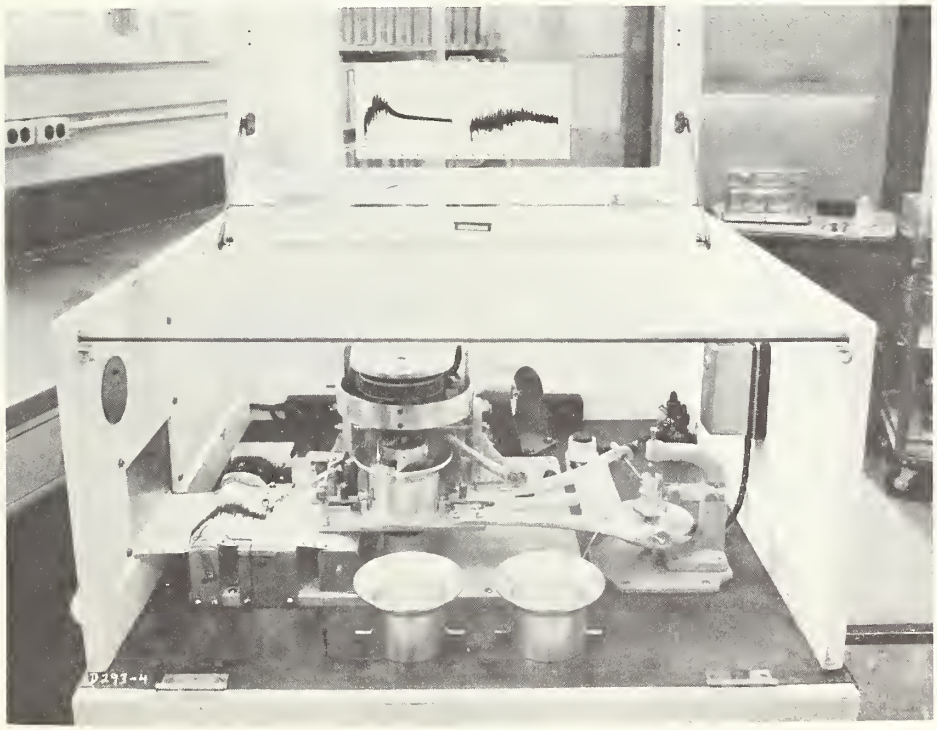


Fig. 4 Mixograph for recording mixing properties of 35-gram flour samples of wheat varieties.

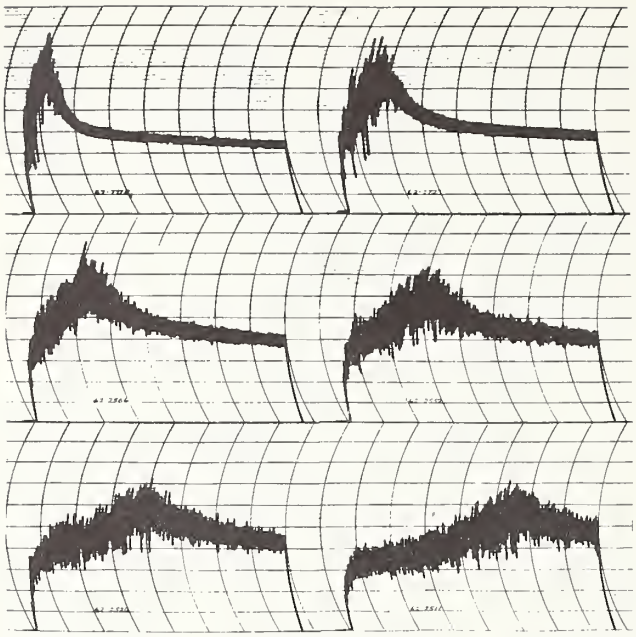


Fig. 5 Typical mixograms of hard winter wheat flours that vary in mixing requirement (time to peak) and tolerance (slope after peak). Arcs are at 1-minute intervals.

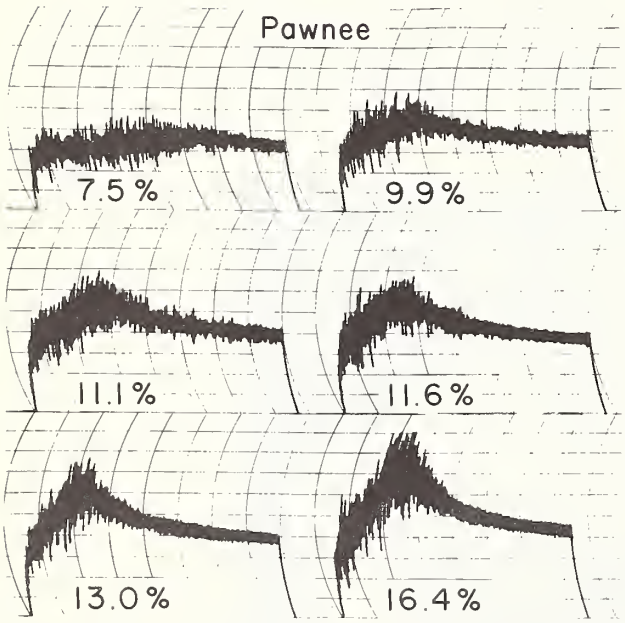


Fig. 6 Effect of flour protein content on mixogram characteristics of Pawnee, a short-mixing hard winter wheat flour.

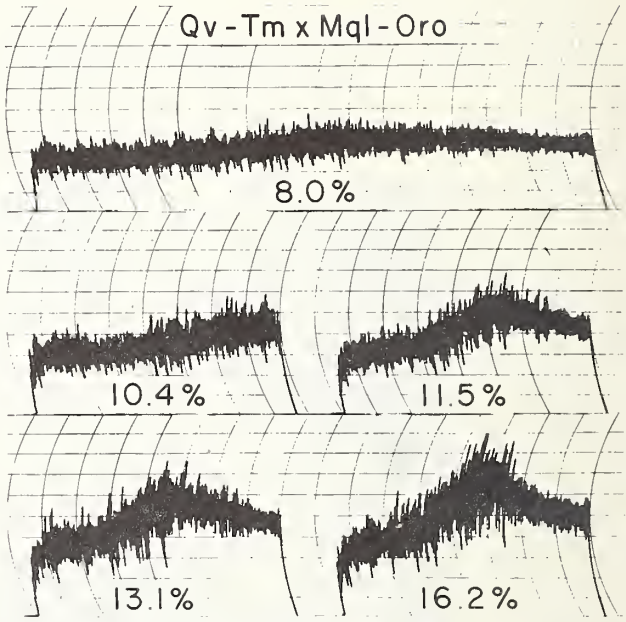
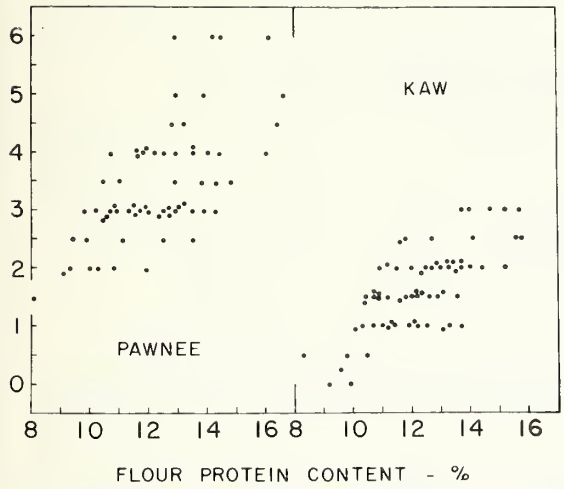


Fig. 7 Effect of flour protein content on mixogram characteristics of Quivira-Tenmarq x Marqui Oro, a long-mixing hard winter wheat flour



. 8 Relation between oxidation ($KBrO_3$) requirement and flour protein content of Pawnee and Kaw, short- and medium-long-mixing hard winter wheat flours, respectively.

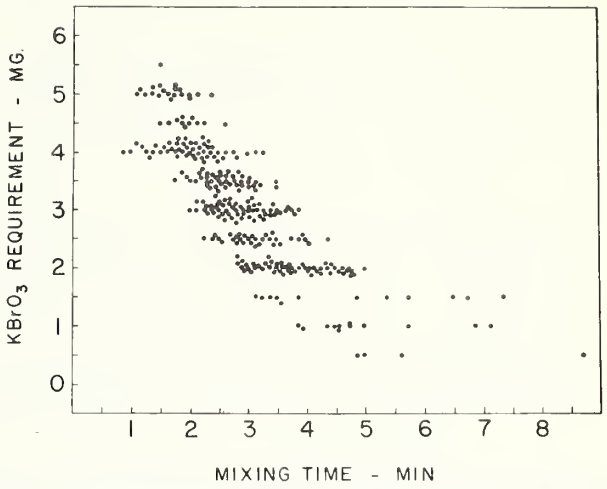
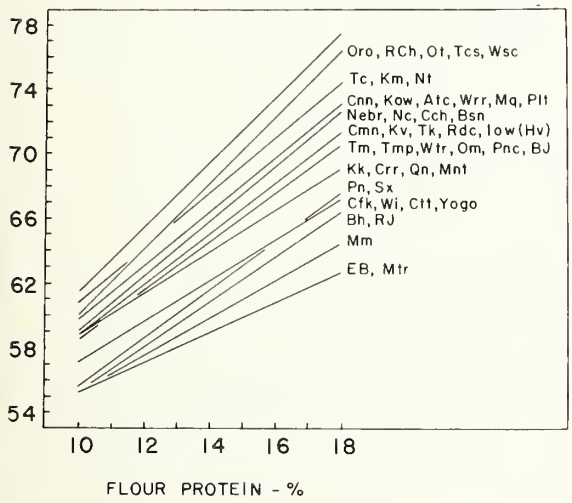


Fig. 9 Relation between oxidation ($KBrO_3$) requirement and mixing time of hard winter wheat flour composites representing a narrow range in protein content and a wide range in other baking quality characteristics.



. 10 Flour absorption-protein regression lines for 42 hard winter and 3 hard spring wheat varieties. Each variety regression line represents many samples harvested throughout the Great Plains during several crop years.

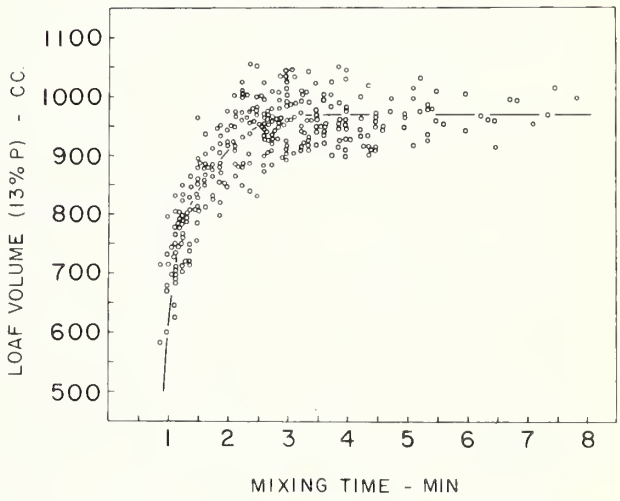


Fig. 11 Relation between loaf volume at the 13% protein level (protein quality) and mixing time of hard winter wheat flours representing a wide range in baking quality characteristics. Samples with flour protein contents of about 11% and less were omitted to avoid their abnormally long mixing times.

HYBRID WHEAT AND ITS IMPLICATION TO WHEAT PRODUCTION

L. W. Briggle, Research Agronomist
Crops Research Division, Agricultural Research Service,
USDA, Beltsville, Maryland

Man has recognized for nearly two centuries instances of superior performance of hybrid plants over naturally propagated plants. The same phenomenon has been observed in animals for perhaps 2,000 years. The German Botanist Koelreuter hybridized plants as early as 1760 and was amazed to note the marked increase in size of some hybrids over that of the parent plants involved. Darwin was another early experimenter. Our modern concept of hybrid vigor (heterosis) became established in 1907 through the work of Shull.

Hybrid vigor, or heterosis, is an increased developmental stimulus which often (not always) occurs in a hybrid in one or more of its characters. A hybrid can be defined as an offspring of parents which have unlike genetic constitutions.

Current use of hybrid vigor in plant improvement was sparked by the marked success of hybrid corn. Today most of the world's sugar is produced by hybrid sugar cane or hybrid sugar beets. Sorghum, onions, and a number of forage and turf-grass hybrids are grown on a large scale.

Recent discoveries have stimulated interest in and speculation concerning the possibility of hybrid wheat being grown on a commercial scale. Plant breeders have been making wheat hybrids for years in the process of developing improved varieties, but this has been restricted to a very small-scale activity. Hybridization of wheat has been, of necessity, a tedious hand operation. By crossing two varieties of wheat, neither a superior variety in itself, breeders have attempted to combine the desirable characteristics into one new variety. They have been successful in a remarkable number of cases. Most of our modern wheat varieties exemplify such a procedure. Perhaps you are familiar with such varietal names as 'Pawnee', 'Triumph', 'Knox', 'Seneca', 'Gaines'--all of which are hybrid DERIVED varieties. Let me emphasize that word derived. The word hybrid is often erroneously applied to current commercial varieties of wheat. No wheat variety grown on a commercial scale today--anywhere in the world--is a true hybrid. The representative commercial variety is a pure line which breeds true from one generation to the next. A hybrid segregates into many different plant types when advanced one generation.

Wheat is normally self-pollinated. A spike (head) contains individual flowers, each of which possesses both male and female parts. Pollen, when shed from the anthers, falls onto the stigma, and in the course of hours the fertilization process is completed. In about 30 to 35 days a mature kernel of wheat is produced from each fertilized flower. In order to make a cross

the wheat breeder must manually remove the anthers before pollen is shed, thus averting self-pollination. At the time the stigma is receptive he places pollen from a different variety onto the stigma. The wheat kernel which develops will produce a hybrid plant. Obviously hybrid wheat seed cannot be produced on a commercial scale by such a procedure.

The recent discoveries referred to earlier are cytoplasmic male sterility and restoration of fertility. These are tools which can be used to produce hybrid seed in quantity. The same tools are now used in commercial production of hybrid corn and hybrid sorghum seed.

Cytoplasmic Male Sterility

Cytoplasmic male sterile plants have shrunken anthers which fail to release pollen (or what little pollen is produced is nonviable). This condition is unique in that it is heritable only through the female parent. Such plants produce no seed unless pollen from other plants is available. Thus the breeder can cross two varieties of wheat by eliminating the tedious and time-consuming task of manually removing anthers to prevent self-pollination. Wheat flowers, when not pollinated in a reasonable length of time (approximately 2 days), normally will open. The glumes (chaff) separate, thus exposing the receptive female stigma. If viable pollen grains are placed on the stigma manually, or if windborne pollen is deposited on the stigma, cross pollination can result and a hybrid seed will be produced. The hybrid plant from this seed will also be male sterile and thus itself produce no seed unless the male parent of the cross had a particular genetic constitution.

Maintainer Lines

Cytoplasmic male-sterile varieties cannot be propagated by self-pollination. A nonfertility restoring variety must be used as the pollinator parent. All progeny from such a cross would be male sterile. Those male-sterile progenies can be grown in a crossing field alongside rows of the original nonrestorer (fertile) variety. Seed harvested from male-sterile rows would produce male-sterile plants in the next generation. Seed harvested from nonrestorer but fertile rows would produce fertile plants, which would be used as pollinator parents in the next cycle. The nonrestorer counterpart functions in propagation of cytoplasmic male-sterile plants. It is often referred to as the "maintainer line."

Restoration of Fertility

The second discovery which shows promise as a tool in mass production of hybrid seed is the existence of specific genes in wheat which can bring about restoration of fertility in the hybrid plant. In effect the fertility

restoring genes from the male parent "overrule" the cytoplasmic male sterility character inherited from the female parent, and normal anthers with viable pollen are produced on the hybrid plant. Only when the male parent of the cross bears such dominant fertility-restoring genes will the hybrid plant be able to self-pollinate and thus produce seed. Through use of cytoplasmic male sterility and genes for restoration of fertility the plant breeder can virtually "turn off" pollen production and later "turn it on" again when needed.

Sources of Cytoplasmic Male Sterility and of Fertility Restoring Genes

Both of these "tools" were transferred to common wheat from related species which differ from wheat in chromosome number and in plant characteristics.

Japanese scientists, beginning in 1951, transferred cytoplasmic male sterility from Aegilops ovata, a grasslike relative, into durum and common wheats. This same source was introduced into some U. S. wheat varieties by Kansas State University and USDA scientists in 1961. They also discovered a second source in crossing Triticum timopheevi with 'Bison', a well-known hard red winter wheat.

The Japanese reported in 1955 and in 1958 that a variety of emmer, when used as the male parent, restored fertility in crosses involving durum and a second emmer, both of which were cytoplasmic male sterile. In 1962, University of Nebraska and USDA researchers found cytoplasmic male sterile plants and fertile plants in a common wheat derivative of Triticum timopheevi. Later observations have confirmed presence of genes for fertility restoration in the population. Kansas State University workers likewise found genetic restoration of fertility in their Triticum timopheevi derived stocks.

Seed of cytoplasmic male sterile genetic stocks, maintainer lines for these stocks, and those possessing genes for restoration of fertility have been distributed worldwide by Kansas State University, the University of Nebraska, and the Crops Research Division, ARS, USDA.

Hybrid Vigor in Wheat

A third requisite for production of hybrid wheat on a commercial scale is an increase in yield of the hybrid over standard varieties. This must be sufficient to warrant the added expenditure for hybrid wheat seed. Experiments conducted to measure heterosis in wheat date back to 1919, but because of the difficulty encountered in producing hybrid seed by hand, tests have been on too limited a scale to be directly applicable to conventional methods

of growing wheat. In very recent experiments we have grown wheat hybrids side by side with parent varieties in hills at different rates of sowing. Hybrid plants yielded from 18 to 41 percent more grain per hill than the average of the parents in one experiment. In another experiment (different varieties were crossed) there was no difference in performance between parents and F_1's. Hybrids involving some of the highest yielding commercial wheat varieties (both winter and spring) were grown in short nursery rows at six rates of seeding. This experiment was conducted by the USDA at Aberdeen, Idaho, in 1963. Data have not yet been analyzed, but the preliminary statement can be made that under irrigation the hybrids produced more grain per row than either parent at every rate of planting. This experiment will be repeated in 1964 and 1965. In the near future full-scale nursery and field experiments can be conducted in an effort to get more representative data on performance of hybrids versus the parent varieties. This will be possible through use of cytoplasmic male sterility, so-called maintainer lines, and genes for restoration of fertility.

Cross-pollination in the Field

Reports in the Russian literature indicate that as early as 1946 cross-pollination of wheat under field conditions was investigated. Since natural male sterility was not available they removed anthers from plants used as female parents (emasculation). In 1961, Texas Agricultural Experiment Station workers placed four cytoplasmic male sterile plants out in the field adjacent to rows of fertile wheat which served as a source of pollen. Hybrid seeds numbering 37, 40, 50, and 83 were produced on the male sterile plants. Kansas State University wheat workers obtained an average of 71 percent seed set on male sterile plants which had been placed 2.5 feet, 5 feet, or 7.5 feet from pollinator plants grown in the field. Virtually the same degree of seed set was obtained through windborne pollen over each distance.

Outlook for Hybrid Wheat

It is impossible to state at this time that hybrid wheat will or will not be grown on U. S. farms. Many questions remain unanswered--more information is needed. The mechanical tools are available, but they remain largely untested. Cytoplasmic male sterile plants, for the most part, have been grown under greenhouse conditions. We know too little about expression of sterility under different environmental stresses present in the field. Much the same limitations apply to the wheat stocks which possess genes for restoration of fertility. Preliminary genetic investigations indicate that inheritance of fertility restoration is not simple; that is, more than one gene is involved. Transfer of genes from one variety or line to another is much easier if only one gene controls expression of the character. Too little is known about the degree of expression of hybrid vigor in wheat. We do know

that some varietal combinations result in considerable heterosis, some result in none at all, and some hybrids produce less than either parent. A few combinations are lethal. Just how much heterosis would be required to make hybrid wheat an economical venture cannot be answered. No information is available at present. Knowledge of cross-pollination under field conditions is meager.

In spite of all the aforementioned limitations, there is much interest in hybrid wheat. Time is needed to learn how to manipulate the tools available, to study economics and procedures of seed production on a large scale, and to develop the best management practices. The mere possibility that hybrid wheat may become a reality is a challenge to the wheat breeder, the commercial seed producer, and the wheat grower. With concerted effort on the part of each, there is a very good chance that hybrid wheat will be grown on some American farms.

What Hybrid Wheat Would Mean to the Breeder

The wheat breeder would be confronted with the task of transferring cytoplasmic male sterility into some varieties and experimental lines, propagating those male sterile plants through use of maintainer lines, and transferring genes for restoration of fertility into others. In effect, two independent series within a breeding program would be required. He would, however, have a ready-made group of "inbred lines," since wheat is self-pollinated. Those combinations of cytoplasmic male sterile lines with fertility-restoring lines which expressed sufficient heterosis and desirable characters such as baking quality and good agronomic traits could be considered as potential commercial wheat hybrids. Advantage could be taken of valuable dominant genes for disease or insect resistance, since only one parent of a hybrid would need to possess the dominant gene. If a reservoir of male sterile and fertility-restoring lines were available, new hybrid combinations could be quickly released in case of an emergency.

The best combining parents may not result in the best hybrid so far as milling or baking quality is concerned, or in such desirable agronomic traits as strength of straw. The breeder could face new problems in maintaining or improving quality and performance. State, Federal, and commercial quality testing laboratories may play an even bigger role in varietal evaluation than before.

What Hybrid Wheat Would Mean to the Seed Producer

Commercial seed companies would certainly play a bigger role in wheat seed production and marketing than heretofore. Since the grower would need new hybrid seed each year there would be an established outlet. Very likely some of the larger seed companies would conduct wheat breeding programs of

their own. In fact, a few companies are already actively engaged in exploratory work on hybrid wheat.

The commercial seed producer would be the one to employ, in a practical sense, those tools (cytoplasmic male sterility along with maintainer lines and genes for fertility restoration) made available by plant scientists. Production of hybrid wheat seed under isolation would probably be patterned after methods used in production of hybrid corn and hybrid sorghum seed. Rows of male sterile plants of one variety or line of wheat would be alternated with rows of a pollinator parent which would contribute genes for restoration of fertility. If fertility restoration was not introduced at this point, hybrid plants grown by the farmer would bear no seed.

The seed producer would propagate, under field isolation, male sterile lines through use of maintainer lines. No particular difficulty would be encountered in propagating fertility-restoring lines, except that adequate isolation of an increase field would be necessary.

Much has yet to be learned concerning procedures effective in producing hybrid wheat seed under field conditions. It is possible that crossing fields will have to be grown in restricted geographical areas where climatic conditions are conducive to high seed set. Ratios of cytoplasmic male sterile rows to pollinator rows will have to be established--this may or may not be similar to corn and sorghum crossing fields. The possibility that hybrid wheat seed may be expensive to produce looms as one of the greater problems.

Production of wheat hybrids for forage may be a possibility. Many parental combinations result in plants with increased vigor. Even some interspecific crosses produce highly vigorous plants, but in many cases the hybrid plants are sterile. It may not be necessary to restore fertility in the F_1 generation, since the crop would be grazed or harvested for forage.

If seed cost prohibits use of the F_1 generation other alternatives could be attempted. Blends of seed from a fertility-restored F_1 with seed from a normal (fertile) line may merit consideration. If F_2 (first segregating generation) plants would perform at a high enough level to warrant use of F_2 seed in the grower's field, this too might be an alternative. Any method other than growing the F_1, however, would mean an expected reduction in heterosis and uniformity.

What Hybrid Wheat Would Mean to the Grower

Of immediate concern to the farmer would be the annual purchase of hybrid seed. Certainly the cost of hybrid seed would be higher than that of a variety--how much higher we do not know. If he saved seed from hybrid plants for sowing the following year he would have to expect a decline in yield. His field would be much less uniform than the field of hybrid plants

had been. Outstanding yields of hybrid wheat would be mandatory in order for it to be used by the grower. It takes more seed per acre to plant wheat than it does corn or sorghum, thus wheat seed becomes more expensive than does hybrid seed of either corn or sorghum.

Use of hybrid wheat would probably be restricted to high or moderately high production areas where the potential of hybrid wheat can best be realized. Ample rainfall or irrigation, reasonably high fertility level, and satisfactory soil drainage are some of the requirements for good production. Regions where hazards such as drought occur frequently or where production is consistently low will likely be less suited for hybrid wheat. Under such conditions most growers would be reluctant to invest the additional cost over that of a well-adapted variety.

Summary

Much research remains to be done concerning the feasibility of production of hybrid wheat on a commercial scale. A maximum degree of heterosis attainable and those specific combinations of parents which will express the desired degree of heterosis will have to be determined. Suitable cultural and management procedures based on economics of production must be established. More information is needed on cross-pollination of wheat under field conditions, on the influence of environment on the degree of expression of male sterility and fertility, and on the genetics of fertility restoration. It is possible that new and better sources of male sterility and genes for fertility restoration will be found. Much effort is being directed toward finding answers to the questions remaining. It is possible that hybrid wheat will be grown on some American farms.

QUALITY CONSIDERATIONS IN THE UTILIZATION OF SOFT WHEAT

D. B. Pratt, Jr., Manager, Quality Control
The Pillsbury Company, Minneapolis, Minnesota

Whenever wheat breeders, farmers, cereal chemists, millers, bakers, and food manufacturers are brought together in a meeting such as this one dealing with the utilization of wheat, each of these groups will raise the question of one another - what do you want? The reply will usually be "quality." One of the disadvantages of our highly specialized civilization is the fact that the same word or term will bear an entirely different meaning depending on who is using it, and so it is with quality.

The wheat breeder will look at the quality of his new variety in terms of its suitability to a certain environment. Does the plant stand short or tall in the field? Is the straw strong enough to withstand the weight of well-filled heads? Is it resistant to prevalent insect pests and plant diseases? These are his criteria of quality.

The farmer measures quality in yet another way. He is interested in how much his crop will be worth in dollars when he brings it to market; so his measures of quality will probably be related to factors which will bring him the greatest financial return on his land investment. Such factors as germination, growth cycle, resistance to weather and disease are important to him; but when he figures his income tax at the end of the year, his yield in bushels per acre, the protein premium he received for his wheat, and the grade premium for high test weight, freedom from garlic, weed seeds, etc., tell him whether he produced quality by his standards.

The flour miller will measure quality by those factors which make his job easier. Wheat flour has a market value of about $5 per cwt., while the animal feed byproducts which he produces at the same time have a market value of $1.50 per cwt. He is interested, then, in how the wheat "yields" in terms of more flour and less feed. Is the wheat easy to mill? Does the bran hold together or is it brittle and difficult to clean up in the milling process? Is the bran heavy and tough? Does the endosperm "shell out" easily and reduce in his grinding system easily or is it difficult to apply enough grinding to properly reduce the endosperm middlings? It requires power to accomplish this grinding, so if the wheat has good milling properties, his power costs will reflect this.

Like the miller, the baker will measure quality on the basis of what the product does or does not do for him. The cracker baker wants a flour that will withstand the mechanical handling he subjects it to. If the flour produces a cracker that is too light or fluffy, he can't fit a pound of crackers into the box he has designed for his product. If the cracker is too thin, the crackers won't fill the box, and he becomes guilty of "slack fill."

If he doesn't overfill to overcome this, the housewife may open the box and find cracker meal rather than the whole product. The cookie baker, too, must fit his product to a package, thus spread factor is important to him. He can increase the spread of his cookies by increasing the shortening and sugar in his formula, but these are costly materials and may affect other factors such as crispness, chewiness, or flavor.

In the manufacture of cakes, the baker's formula is adjusted to produce a certain type of product. The "batter" which the baker uses is costly. If because of some failure in flour quality he finds it necessary to overscale or reformulate to achieve desired volume, his profits dwindle.

Finally, the industrial user of wheat flour looks at his material in yet another way. If he is thickening soup or gravy, he wants to accomplish this with as little flour as possible to avoid a "pasty" taste. The stability of the thickened gravy or soup is important - sometimes these products retrograde due to enzyme action. In pie crusts it is the desire of the manufacturer to produce a flaky, tender product containing as little fat as possible. If the crust is to have these desirable characteristics, the fat must remain in the dough as "lakes" which will be absorbed by the flour during baking leaving a void - thus a flaky characteristic in the baked crust. The flour, then, should not absorb the fat at the time the dough is mixed. He has other processing factors that influence his product too - many of them related directly to the soft wheat flour he is using.

When soft wheat flours are used as glue extenders in the plywood industry or as wallpaper paste, still other characteristics become important.

It is readily apparent from these brief remarks that quality considerations cover a very wide and diverse set of conditions. Under these circumstances, then, let us attempt to define quality. Quality can and does mean a variety of things to the ultimate user of the product. It usually represents, however, conformance to a number of measurable characteristics which experience has indicated are significant in terms of end use. A more concise definition of quality, then, is the ability of the product (in this case, wheat or flour) to produce an attractive end product at a competitive cost under those conditions imposed upon it by the end product manufacturing facility.

No mention has yet been made of the cereal chemist and what he wants in terms of quality. This omission was intentional. It is not difficult to describe what everyone else wants, but it is extremely difficult to be in the situation of describing one's own wants, particularly when, as a middleman in the economy of wheat utilization, it seems almost a predestined dictum that the candle be burned at both ends.

With your indulgence, may I describe some of the criteria of quality which the chemist looks at in wheat and flour and attempt to relate some of these measurements to end usage.

GPO 809-570-4

The most recent edition of CEREAL LABORATORY METHODS describes in detail some several hundred tests which, when properly applied, measure certain of the characteristics of wheat or flour. Not all of these tests are applied to each sample of wheat or flour. Instead, certain of them, which experience, both sad and happy, has shown us are helpful in relationship to a certain type of end use, are employed, and they thus assume importance as quality measurements. When one considers the wide scope of use, it is easy to understand that each measurable factor will carry a different weight in establishing an overall estimate of whether a product does or does not meet our definition of quality.

Let us look first at those quality factors which the miller feels are significant to him. Since he is judged by his milling figures and his ability to produce an end product that conforms to certain specifications, he is interested in test weight per standard bushel, uniformity in kernel size, experimental milling data which can be correlated with his commercial unit, endosperm ash (primarily because this will give him guidance in establishing his grinding procedures), freedom from foreign material, and the basic characteristics of the bran coat which should be neither too thick nor too thin and separate from the endosperm easily. Weights of the various flour streams obtained by experimental milling will guide him in terms of whether the endosperm chunks will reduce to flour easily or with difficulty. If he is employing air classification, this same information will guide him in predicting how successfully he can "shift" protein. We chemists are now throwing some new obstacles in his path, such as the amount of starch damage he manages to accomplish during the milling process. Unfortunately, some types of end use require more starch damage than others - so the chemist is crazy - he doesn't know what he wants. I suppose we'll further enhance this opinion of ourselves as we apply more tests to further confuse him.

As a group, we are all interested in protein. It's highly nutritious and does not increase our waistlines. In wheat, we are interested in protein from the standpoint of quantity which is easily measurable by the classic Kjeldahl test, and in protein quality which is a bit more difficult to appraise. Our colleagues involved in research studies of wheat proteins will report their progress during this meeting, and, if their progress has continued along the same lines as they have previously reported, we will learn that the amino acid building blocks for wheat proteins are the same in many, if not all, classes of wheat. Yet we know that these proteins behave differently in end performance and can point out measurable differences in rheological behavior. The protein "house" can have the same number of rooms and cubic area - what we don't know is whether we have a colonial two-story house, a ranch-type rambler, or a split-level. How the blocks are assembled may account for these observable differences. One might also suspect a significant performance influence due to the ratio of water soluble to total protein since we have observed that this relationship does change between wheat classes and within a single class between varieties, which do perform differently. Air classification techniques have helped us here. For example, a 20-percent protein fraction from certain midwestern soft wheats will contain as much as

30 to 35 percent of its total protein in a water-soluble form, while a similar 20-percent protein fraction from intermountain soft white wheats will contain only 15 to 20 percent of its protein in the water-soluble form. Certainly it may be very likely that this difference is significant in explaining some of the performance differences we observe between these two varieties of wheat.

During the past several years a great deal of new research work has been devoted to the starch of soft wheat. This is certainly a factor to be considered in evaluating quality. One of the measurements employed in the laboratory today is that of determining starch damage. This damage is significant as a factor influencing end performance. For example, as the starch damage is increased, in the same cookie flour, by mechanical means, the spread factor as determined by a standard cookie test decreases. In a cake flour the overall performance of the same flour is improved by mechanically increasing the starch damage. Although, as a quality factor, the presence or absence of starch damage is something which occurs during processing and may be controlled to some degree, the mellowness of the endosperm is a genetic factor. Some soft wheats are capable of endosperm reduction to a very fine particle size without extensive damage to the starch. Others, which tend more toward the vitreous type endosperm, require considerably heavier grinding pressures to reach the same degree of fineness in terms of particle size, and, when this is the case, starch damage is significantly higher.

The behavior of starch can be modified during processing by chemical means as well as physically damaging the starch. Recent work at the soft wheat laboratory at Wooster, Ohio has studied the fate of chlorine gas when added to a soft wheat flour. Although the chloride residue is formed in all the component parts of the flour, it appears that only that portion of the chlorine which acts upon the "prime" starch is effective in changing the performance of the flour. The research laboratories of the British Baking Industries have made similar studies and further report that the swelling properties of prime starch treated with chlorine gas are as much as three times greater than untreated starch. This group attributes the improved performance of chlorine-treated cake flours to this phenomenon by theorizing that the increased swelling power facilitates the retention of CO_2 gas within a cake during the baking process. This same observation might also explain why chlorine treatment reduces the cookie spread of a soft wheat cookie flour; i.e., more of the water is taken up by the starch and is thus not "free" in the cookie dough to form a sugar-water combination and allow the dough to spread during baking.

Particle size of the finished flour is another quality consideration, but I am not sure that we are ready to draw the conclusion that in its own right this factor has a great influence. My own suspicion is that the performance changes one observes due to differences in particle size might well be related to other changes which are brought about concurrent with the change in particle size; i.e., fine grinding usually increases starch damage; it also will release more free protein from the matrix which surrounds the starch and thus increase the available surface area of free starch particles for hydration.

Enzymatic activity is another important quality factor for certain end uses. When this factor is low in the wheat or flour, there is no problem in elevating the level, if this is desired, by the addition of supplements. There is no practical way to remove excessive activity which is objectionable. Rather high levels of activity seem to have little or no influence on cake or cookie production; however, a drastic and sometimes disastrous influence is brought about in crackers, soups, and gravies. In cracker production, where long yeast fermentation is involved, excessive amylase converts too much of the starch into sugars or intermediate products which affect the flavor and the texture of the finished cracker. In addition, the higher level of protease which usually accompanies the higher amylase level degrades the protein excessively resulting in poor machining properties - doughs lose their extensibility, resulting in a high level of cripples or unsaleable merchandise.

When flour is used for the purposes of thickening soups or gravies, a high level of enzymatic activity results in a normally acceptable product at the time of processing; degrading during even short time storage. This degradation is evident in the soup or gravy becoming quite thin and watery or as a "curdled" appearing product. Starch damage is also a factor here since the damaged starch is more readily susceptible to the action of the enzymes. Usually the quality measurement which seems to be of value is hot paste viscosity of a flour-water suspension (the Amylograph).

We do not know whether quantity of enzyme is genetic insofar as the wheat is concerned, but we are all well aware that moisture after the wheat is ready to harvest can start germination of the wheat before it is combined. At the onset of germination the enzyme level in the wheat increases dramatically even though visual inspection does not indicate that anything has happened.

If enzyme content is genetic, perhaps its level might be controlled by breeding work. If not, a more rapid maturing or slower maturing variety might be developed with a careful eye on rainfall and when it occurs to lessen the likelihood of germination occurring in the field before harvest.

Viscosity of the flour produced from soft wheat is another quality consideration. This measurement as it is made today is somewhat confusing since protein quantity and starch damage are both a part of the viscosity reading. Lactic acid is employed to cause the gluten portion of the protein to swell while intact starch has limited water imbibing properties under the test conditions. If the starch is damaged, its capacity to absorb water is increased, thus increasing the viscosity of the flour-water suspension.

Rheological measurements of flour-water doughs are also of value in ascertaining such factors as water absorption capacity at constant consistency, the rapidity of hydration and some insight into the extensibility and resistance to mechanical breakdown of the gluten protein. Except in cracker production, it is very doubtful that gluten is ever mechanically developed completely and it is thus in this application that extensibility and breakdown are important. Rate of hydration and absorption are important in cakes, cookies,

and pie crusts, so rheological measurements are important considerations.

In certain end uses, primarily when the flour is employed in the manufacture of frozen uncooked foods, industry is fast becoming aware of a need to control the microbiological population of the raw materials used in preparing its products. We must look, then, both at controlling this population in the unprocessed wheat and the flour. How this can be accomplished is the subject of work presently being undertaken.

The work which the Peoria Laboratory has been doing in the area of in-process chemically modified starches for use in the paper and textile industry has been very fruitful in terms of producing desirable products. Economic factors remain a question still unanswered. However, there is little question that some of the quality factors mentioned here will be of importance in these new areas of industrial use.

Time and my own limited knowledge do not permit mention of investigations in progress which undoubtedly will add to the list of quality considerations applicable to the use of soft wheat and products produced from this class of raw material.

The comments presented in this review should point up to those who have granted me their indulgence that there is no hard and fast set of quality factors by which it is possible to predict universal acceptability of a product produced from soft wheat except, and this is mentioned with considerable embarrassment, a performance test which approximates that employed by the consumer. It should also be apparent that any of the quality considerations cannot, at this point in time, be fulfilled with a single variety of soft wheat. The need, then, is for a number of varieties, which can be employed for their own particular peculiarities as these relate to the end use or which may be blended with other varieties to produce a composite blend of quality factors which will fulfill the varied needs of those who use soft wheat.

Hopefully, what has been presented here will be helpful in explaining away the reputation many of us have acquired of not knowing what we want. We do know, but one wonders if, and doubts that, it will ever be bound up in a single package. Certainly, if science is a dynamic field, moving ever forward into the unknown, we will never reach the proverbial "pot of gold" at the end of the rainbow; but we should be able to accumulate more than a few "gems of new knowledge" along the way.

THE POTENTIAL VALUE OF GAMMA RADIATION IN THE WHEAT INDUSTRY

Lloyd E. Brownell, Professor, Chemical and Nuclear Engineering
University of Michigan, Ann Arbor, Michigan

A. Introduction

On August 15, 1963 the Food and Drug Administration approved the use of gamma radiation to process wheat and wheat products for the control of insect infestation. This approval is a milestone for both the wheat industry and the radioisotope industry. This action permits the use of a new process where desired for control of insect infestation in wheat and wheat products such as flours, meals, and combinations of these products. Although the primary use of gamma radiation in the wheat industry is expected to be for control of insect infestation, the use of the process in some instances can be used to modify and improve the baking quality of wheat flours and flour products. This action also opens the door for the use of gamma radiation to process a major food item. The use of this process is expected to grow and include many food items and become an important technique in the food industry.

The preparation of the petition was made possible by several factors, the principal one being the performance of a feeding experiment using irradiated whole wheat grain fed to four generations of experimental rats. The results of this feeding experiment have not been presented at any previous open meeting and have not been published. The findings of this experiment are described only in an internal report of The University of Michigan and in the petition to the Food and Drug Administration. The results of this experimental study should be made available to the wheat industry and other investigators interested in the wholesomeness of irradiated food and will therefore be presented briefly here.

B. Irradiated (10,000 rep) Whole Wheat Fed to Rats at the University of Michigan (1)

The Food and Drug Administration of the U. S. Department of Health, Education, and Welfare has recommended that studies on the wholesomeness of irradiated foods be directed along two major lines of approach; nutritional adequacy and potential toxicity (2). The nutritional adequacy of gamma irradiated wheat and wheat products was investigated at the University of Michigan and will be discussed in this section.

The insect deinfestation dose of 20,000 to 50,000 rad used in the FDA petition for wheat is very low, some vitamins of principal importance in wheat, such as thiamine, would be protected because of the low level of moisture in wheat grain, whereas destruction of fat-soluble vitamins such as Vitamin E is promoted in the presence of peroxides from irradiation of the wheat germ oil.

Because of the critical role Vitamin E plays in the reproductive process, it was felt that feeding experiments designed to test the reproductive performance of animals would serve as a means of indicating the absence of toxic properties of irradiated wheat as well as indicating that Vitamin E, and presumably the other vitamins, had not been significantly reduced in content by the mild dose of gamma radiation used. The Vitamin E content of whole wheat varies from 1 to 6 mg./100 gm. If wheat of the highest tocopherol content is fed at about 70 percent of the diet, the minimum requirement for this vitamin is just met for the most demanding phase of reproduction in rats, namely, lactation, the requirement for which is 0.75 mg./day. The feeding experiment was designed to permit observations on the growth, reproduction performance, and pathology of four successive generations of rats.

The radiation dose required to break the life cycle of most insects by interference with reproduction is about 5,000 to 10,000 rad (see Section C). Therefore, in the animal feeding experiments at Michigan using irradiated whole wheat a Co^{60} gamma dose of 10,000 rep was used. This dose may prove adequate for various areas and certain wheat products. A few insects found in wheat and wheat products may require a dose of 17,000 rad and to encompass all such insects the minimum dose specified in this petition has been increased to 20,000 rad.

The wheat used was a mixture of soft white wheat and winter durum. It was irradiated in the form of the whole intact grain, inasmuch as this is the form which would be irradiated commercially. The wheat was exposed to a Co^{60} source of gamma radiation having a flux of 180,000 rep./hr. It was stored at room temperature for a period of 1 to 3 months prior to feeding. Just before mixing into the diet, it was coarsely ground. The wheat fed to the fourth-generation animals was stored for 6 months at 80-90° F. to test adverse storage conditions on the nutritional value of irradiated wheat.

Whole grain wheat does not by itself constitute an adequate diet for the rat, as it must be supplemented by additional protein, lysine, tryptophane, calcium, salt, iron, Vitamin A, and riboflavin and other B vitamins. An excellent protein supplement which does not supply significant quantities of Vitamin E is skim milk powder with added quantities of casein, which furnishes the B vitamin requirements, but not in excessive amounts. The remaining requirements of minerals can be supplied as salts. The diet used thus had the following composition:

Coarsely ground wheat	70%
Purified casein	14%
Skim milk powder (spray dried)	15%
Calcium carbonate	0.75%
Sodium chloride	0.25%
Ferric citrate	0.09%

The only supplement was that of Vitamin A in 0.1/ml. corn oil given orally to each rat each week, which supplies less than .08 mg. Vitamin E.

The diet containing irradiated wheat and a control diet, identical except for the irradiation step, were each fed to a group of 12 male and 20 female Holtzman strain albino rats. The rats were maintained individually in wire-bottom cages and given water and diet ad libitum. The rats were checked daily and weighed weekly. At 12 weeks of age, male and female rats were mated in weekly rotation. Pregnant females were isolated on shavings in cages until 14 days following the birth of a litter, when the family was transferred to a wire-bottom cage. Litters over 10 were reduced to that number 7 days following birth. Animals were weaned at 21 days.

The second-generation colony was composed of 20 females, at least one from each litter, and 12 males, selected from the 12 litters with the most males. The first generation was bred again to obtain additional data on reproductive performance, but the offspring from the second breeding were discarded. The second and third generations were bred in the same manner as the first, and the third and fourth generations obtained in the same manner as the second. The fourth generation was bred only once.

Autopsies and histopathological examinations were made on nearly all rats when found dead or requiring sacrifice during the experimental period. Histopathological diagnoses were made by courtesy of members of the Department of Pathology, School of Medicine, The University of Michigan.

1. Results

The growth curves of the male and the female groups fed each diet for all four generations are shown in Figure 1. The vertical width of each curve represents the standard deviation above and below the mean for the group. In some cases, animals were not weighed after the beginning of the second breeding because pregnancy rendered comparisons between groups of little significance.

Good growth was obtained with all four generations of rats fed this diet. The 12-week mean weights for the males and females of each generation were fairly uniform, except that the growth rate of the fourth generation was somewhat higher. It was this generation which was fed the wheat stored for 6 months after irradiation at 80-90° F. This rate of growth compares favorably with that of rats fed standard laboratory chows. These 12-week mean weights are shown on the table below.

Generation	Males	Females
First	295 g	190 g
Second	305	190
Third	295	200
Fourth	335	215

There appear to be no consistent differences in growth rate between animals fed the irradiated and nonirradiated wheat. In most cases, the band of standard deviation overlaps, and where it does not, animals fed the irradiated wheat have the higher body weight. This is true of the first three generations of males, but not of the fourth. There appears to be no significant difference between the groups of females during the period of active growth.

2. Reproductive Performance

Table 1 is a summary of the data on reproductive performance for all four generations of animals. The overall performance of the animals indicates that the diet as formulated is satisfactory in spite of poor survival of young from the second generation. The diet containing the irradiated wheat resulted in superior performance in nearly every case where a substantial difference in values was observed. This is especially true of the suboptimum performance of the second generation male. The paternity of males was established assuming a 22-day gestation period, and it is noteworthy that the percentages for all male groups were high.

As noted later, the members of the second and third generation were inadvertently given 100,000 IU dose of Vitamin A at one time, and this occurred between the first and second breeding of the second generation and while the third generation was very young. It can be seen that, with respect to percent pregnancy and to percent of pregnant females giving birth, the performance during the second breeding is suboptimum, possibly as a result of the Vitamin A overdosage which is known even in doses as low as 10,000 IU to affect vaginal and uteral epithelium. The survival and body weight of the pups appeared not to be affected. The reproductive performance of the third-generation females was superior to that of the second generation in all respects other than rate of pregnancy, and this improved during the second breeding, an indication that any aftereffects of the Vitamin A were dissipated.

3. Pathology and Mortality

Of the 248 animals involved in this experiment, death occurred or sacrifice became necessary for 10 at random intervals throughout the 18-month experimental period. None of these animals was kept beyond 37 weeks of age; therefore this mortality was not due to old age. During one 4-week interval, however, an additional 17 animals were lost following an accidental overdose of Vitamin A followed in turn 1 week later by a temporary, but precipitous, drop in temperature of the animal quarters. The mortality from this cause was divided equally between control and experimental groups. Gross observations were recorded at autopsy for 5 of these 27 animals, and histopathological diagnoses were made in the Department of Pathology at The University of Michigan's Medical School on the heart, lung, liver, spleen, stomach, pancreas, small intestine, adrenal, kidney, and genital organs for all but seven in which postmortem changes were too pronounced. Dr. Ruth Wanstrom, Dr. Robert Hendix, and Dr. A. James French of this department performed the histological diagnoses and were most helpful in their advice during the experiment.

TABLE 1.--Data on reproductive performance

	1st Generation				2nd Generation			
	First breeding		Second breeding		First breeding		Second breeding	
	Control	expt.	Control	expt.	Control	expt.	Control	expt.
No. of females bred	20	20	20	20	20	20	19	20
No. of males used	12	12	12	12	10	10	10	10
Percentage of males whose paternity was established	91.6	91.6	100	91.6	60	80	70	100
Percentage of females bred which appeared pregnant	100	100	100	100	100	100	89.4	85
Percentage of apparently pregnant females which gave birth	95	100	100	100	95	100	82.3	88.2
Avg. No. pups born/litter	8.3	9.5	10.2	11.0	8.9	9.2	6.9	8.3
Percentage of pups born surviving the first day after birth	92.7	87.8	98.0	92.7	63.9	76.1	64.5	70.1
Percentage of pups surviving first day which survived 21 days	79.7	85.5	75.5	79.4	55.5	82.1	69.3	68.9
Avg. body wt. at weaning (21 days)	41.0	37.5	42.4	41.9	36.9	38.7	47.2	49.6

TABLE 1.--Continued

	3rd Generation				4th Generation	
	First breeding		Second breeding		First breeding	
	Control	expt.	Control	expt.	Control	expt.
No. of females bred	19	18	18	18	24	24
No. of males used	8	9	7	9	12	12
Percentage of males whose paternity was established	87.5	100	100	100	91.7	100
Percentage of females bred which appeared pregnant	89.4	94.4	83.3	88.8	100	100
Percentage of apparently pregnant females which gave birth	100	100	100	100	95.8	95.8
Avg. No. pups born/litter	8.9	8.2	9.5	9.8	9.6	10.2
Percentage of pups born surviving the first day after birth	95.4	95.7	97.1	95.5	82.3	88.0
Percentage of pups surviving first day which survived 21 days	88.2	79.1	77.5	81.3	77.3	85.0
Avg. body wt. at weaning (21 days)	43.6	42.0	38.3	40.0	38.2	37.1

With regard to the 10 animals, 7 males and 3 females, lost prior to or well after the period of Vitamin A overdosage, histopathological data is available on 5 males, the other 2 males and the 3 females having suffered postmortem changes too extensive for histopathological examination.

There was nothing significantly abnormal at autopsy except for a small prostate hemorrhage in two of the five males, one of which had a hemorrhage behind the jaw and below the brain. There was no lipidosis in any heart tissue specimens, and acute passive congestion in only one (control). Atelectasis and/or emphysema were present in lung specimens from two controls and one experimental, and bronchial inflammation present in one control and one experimental. Lipid was absent in all specimens.

Hemosiderosis was reported in spleen specimens from two controls, and marked acute passive congestion in another. Decreased numbers of lymphocytes were reported in a specimen from an experimental animal, while the other was negative. The stomach, small intestine, and pancreas on all specimens were negative. Moderately heavy to marked lipidosis occurred in liver specimens from one control and two experimentals, the other two controls being negative. Acute passive congestion was present in two controls. Lipidosis was present only to a slight extent in one kidney specimen, while ischemic glomeruli was observed in one control and one experimental. Active spermatogenesis was reported in one testis specimen from a control animal, while spermatozoa were not present in specimens of seminal vesicles from two experimentals. The seminal vesicles of the control male with the hemorrhage behind the jaw was distended with fluid, and the epididymis had hemorrhage around the tubules.

The following is a summary of the pathological findings in the 17 animals whose death was related to the Vitamin A overdosage in which they were accidentally given 100,000 units in place of the regular 100-unit weekly dose. Although this incident was not planned in the experiment, the results are of interest because sufficient stress was placed on the two colonies of animals to cause death to 17 animals. Subtle effects of feeding an irradiated diet might possibly appear as a result of such a level of stress. Of the 17, 8 were from control groups, 9 from experimental; 11 were from the second generation with an age range of 36 to 41 weeks, 6 with an age range of 12 to 14 weeks were from the second generation; 13 were males, 4 were females.

Many of these animals, especially those which were most chilled when the thermostat failed on the air conditioner, were found suffering from acute respiratory difficulty just before death. Various forms of hemorrhage were the most frequent observation at autopsy. Hemorrhage involving the urogenital area was observed in six males (3 control, 3 experimental), one of which had testicular inflammation (experimental). Bleeding around the spleen was seen in two (both controls). The left lung in one male (control) was engorged with blood; in another (control) there was a large clot near the aorta; in a third (control), there was thin bloody fluid in the peritoneal cavity. No abnormalities were noted in the four females at autopsy.

No lipidosis was reported in any heart tissue specimens; congestion was found in specimens from three males (2 controls, 1 experimental). Five specimens from males (2 controls, 3 experimental) were reported entirely negative. Subepicardial purulent inflammation and hemorrhage was reported in one animal having testicular inflammation (experimental). One animal whose left lung and left testis was engorged with blood was found to have an interstitial subendocardial and subepicardial hemorrhage (control). Two females (1 control, 1 experimental) showed evidence of calcification in heart tissue.

Severe, acute, purulent bronchitis or pneumonitis was found in lung specimens from three males (1 control, 2 experimental). Acute edema and/or congestion was found in four (2 controls, 2 experimentals). Lipid was observed in three specimens, abundantly in one specimen associated with acute purulent bronchitis and pneumonitis, moderately in another control with inactive bronchitis, and in phagocytes of an experimental female which had atelectasis in the lung along with a focus of a chronic granulomatous inflammatory process. Another experimental female had emphysema and acute passive congestion of the lungs; the blood took on a heavy fat stain, which is unusual. A control female had chronic lobular pneumonitis with significant activity. There was no lipid, but acute passive congestion.

Hemosiderosis was observed in spleen specimens of seven males (3 controls, 4 experimentals); hematopoiesis in one (control). Two were reported negative (one control, one experimental). Hemosiderosis was present in spleens from three females (1 control, 2 experimentals).

The stomach, small intestine, and pancreas were negative on all specimens submitted from this group, both males and females.

Liver specimens from all males were negative except for degrees of lipidosis observed in specimens from two controls and two experimentals. Liver specimens from two females (both experimentals) showed acute passive congestion, with abundant lipid in Kupffer cells of one, and moderate lipid in liver cells near central veins.

Adrenal gland specimens showed decreased cortical lipid in three cases from controls and three from experimental; one specimen from an experimental animal had abundant cortical lipid. One female had a small, somewhat granulomatous inflammatory focus in adipose tissue adjacent to the adrenal gland.

No lipid was reported in any kidney tissue from males in the series receiving overdosage of Vitamin A. Three controls and three experimentals were reported entirely negative. Two experimentals had some protein in tubules; there was acute passive congestion of one control kidney, blood in the pelvis of another. There was no calcium deposition reported in any specimens from males, but three specimens from females were found to have moderately heavy calcium deposits in convoluted and collecting tubules. Lipidosis was slight in one control and one experimental female specimen, marked in another experimental which also had acute passive congestion. In one female, the renal lesions due to calcium deposition were extensive enough to cause death.

Spermatogenesis was active in testes from three control and three experimental males, but various forms of hemorrhage were also present in most of these specimens. One control and one experimental had interstitial hemorrhage; two controls and two experimentals had epididymal hemorrhage. In one control and one experimental with hemorrhage, there was decreased spermatogenesis and retrogressive changes in the testes. No findings were reported on specimens of female reproductive organs.

It is abundantly apparent that the effect of the overdosage of Vitamin A did not reveal differences between controls and experimentals, inasmuch as the occurrence of nearly every pathological lesion was evenly divided between the two groups of animals. There has been considerable work on the effect of Vitamin A overdosage on rats, but most of this work involves doses considerably in excess of the 100,000 IU given in this experiment. In addition, most of the past work involves repeated doses to overcome the animal's ability to destroy the greater part of one large dose. When 25,000 IU were administered daily for 100 days no effects were observed except for some decrease in weight. If Vitamin A is toxic, it is in excess of 100,000 IU given daily. However, hemorrhage is one of the usual findings, especially in mucous-secreting tissue, such as lungs and reproductive tissue. Bone fractures, the other common finding, were not noted in these animals.

4. Conclusions

With so few animals lost during the experimental period, and with nearly all the pathological details appearing on both control and experimental animals, it is concluded that the irradiation of the wheat had no effect on growth, reproduction, and pathology when fed to rats for upwards of nine months. No difference between irradiated and nonirradiated wheat is revealed when both are stored under conditions promoting loss of vitamin content and increase in peroxide formation. The Vitamin E content of wheat given 10 kilorep irradiation is adequate to support good reproduction. It is significant that as many controls as experimental animals suffered from the Vitamin A overdosage, since alphatocopherol, among other forms of Vitamin E, tends to mitigate the effect of hypervitaminosis A.

Irradiated whole wheat (10,000 rep) may be considered wholesome and nutritious and as useful as nonirradiated whole wheat in supporting growth and reproduction.

C. Specification of Lower and Upper Limits of the Dosage of Gamma Radiation for Wheat and Wheat Products

1. Range of exposure of gamma radiation to insects infesting wheat

The amount of exposure to gamma radiation proposed for complete deinfestation of wheat and wheat products processed in commercial quantities is specified as a minimum of 20,000 rad and a maximum of 50,000 rad. The proposed lower limit of gamma radiation is based on entomological studies which

assure that the reproductive cycle of insects infesting grain can be broken. However, in a modified procedure using a lesser dose of about 10,000 rad, residual protection for several months may be obtained by the sterile male technique. The advantage of residual protection may indicate a preference for the lesser dosage in some cases.

Before discussing the effects of gamma radiation on insects, a consideration of some of the effects on living cells in general is pertinent.

2. Effect of gamma radiation on living organisms

The effect of gamma radiation on insects infesting wheat and wheat products is complex. All known forms of life can be destroyed if exposed to sufficient dosages of gamma radiation. In general, the simpler the organism, the greater will be its resistance to gamma radiation (see Fig. 2). The influence of gamma radiation on single cells provides a background for an understanding of the use of gamma radiation for the control of insects.

Tissues that "grow rapidly" are more sensitive to the effects of radiation than are the slower growing - those whose component cells divide less frequently. Tissue may increase in bulk as the cells composing them grow larger or by increase in the amount of fluid between the cells; however, when we speak of tissues "growing" we refer, as a rule, to an increase in the number of cells. In man, for example, the most sensitive are the bone marrow cells (which produce blood corpuscles), the cells lining the intestines, and the reproductive cells, all of which grow rapidly. Nerve cells do not divide but only increase in size and are relatively resistant to irradiation. Tumor cells divide more frequently than normal cells. This fact is involved in the use of radiation for cancer therapy: just enough radiation is used to destroy the more sensitive malignant cells without destroying too many normal cells. Single cells which divide at frequent intervals, such as vegetative bacteria, are usually much more sensitive to ionizing radiation than are bacterial spores. For example, the lethal dose for bacterial spores is 10 times that for most vegetative microorganisms. Reproductive cells in insects and the ovum of the egg are more susceptible to radiation damage than the body cells of adult insects.

Single cells exposed to low doses of ionizing radiation exhibit slight changes in the rate of respiration and/or cell division. As radiation dose is increased, characteristic changes occur; different organisms exhibit varying degrees of sensitivity. At the time of irradiation, little effect on single cells is detected, and some time must elapse before the effects of the irradiation become apparent. After irradiation, most cells will respire normally and show other normal biological characteristics. However, irradiation appears to interfere with cell division. Some cells may grow gigantically before dividing; when cell division does occur, the daughter cells do not redivide.

3. Early studies of the effect of ionizing radiation on various insects

Brownell (Ref. 3, p. 273) has given the following review of some of the early studies of the effects of ionizing radiation on various insects.

Hassett and Jenkins reported the effects of gamma radiation from Co^{60} on eight species of insects. Most of these tests were made with doses sufficient to destroy adult insects. The general conclusions made for six species were that a dose of 64.4 krep was lethal to adult insects and that doses of 16 to 32 krep inhibited reproduction. Proctor et al. reported the effect of gamma radiation on the mean survival time of adults of four insect species, as shown in Fig. 2. Dosages greater than 0.30 Mrep were required to kill the insects immediately, but one-tenth of this dose was sufficient to sterilize them. An extensive series of tests were reported by Baker, Taboada, and Wiant. As a result of these studies, the following conclusions, among others, were stated:

"1. An electron dose of 10 krep will sterilize flour beetle and granary weevil eggs, and this same dose will prevent the adults from reproducing.

"2. A dose of 500 krep was lethal to all adult flour beetles immediately after treatment. A dose of 250 krep was lethal to 92 percent of adult flour beetles within 1 week after treatment."

4. Recent studies on the control of insect infestation of wheat and flour by gamma irradiation

Cornwell et al., (4) investigated the effects of gamma radiation on 17 species of insects which infest cereal commodities. In one of the experiments, immature stages of 12 species were irradiated at 20,000 rep (about 18,600 rad). The results (Table 2) show that there was a reduction in emergence of adults in the irradiated cultures, and the insects which survived the treatment were sterile. Among these latter were the Calandra granaria, the Calandra oryzae, and the Tribolium confusum, three of the most destructive insects of stored grain. Another test was carried out to study the tolerance of 13 species to sterilizing doses. One species was sterilized at 4500 rep and six more species were sterilized at 6000 rep. Although the remaining six species were not sterilized at 6000 rep, they produced very few offspring. A dose of 6000 rep was the highest dose level used in this series of tests. A Co^{60} gamma source was used.

Nicholas and Wiant (5) have reported a study of 12 insect species including the 3 specifically mentioned above. They reported that all the adults irradiated at 10,000 rep were fertile, but the average number of second-generation adults was only 17 per pair as compared with an average of 128 for the control pairs. The pairs treated at 40,000 and 160,000 rep were all functionally sterile. No data were obtained for 20,000-rad dosages. In addition, no second-generation forms were found from 284 adult confused flour

beetles all irradiated at 10,000 rep. The work by Nicholas and Wiant also demonstrated that graded resistance within a species is exhibited increasing with the development stage of the insect from egg to adult, thus showing that a dosage that is sufficient to control adults will also control the eggs, pupae, and larvae. Electrons from a 1.0-Mev accelerator were used in this work.

TABLE 2.--Theoretical population decline when sterile males (screwworms) are added to a natural population

Natural population	Sterile males released	Ratio of sterile to fertile males	Population decline (theoretical maximum)
1,000,000	2,000,000	2:1	333,333
333,000	2,000,000	6:1	46,619
46,619	2,000,000	42:1	1,107
1,107	2,000,000	18,000:1	1

Workers in the Soviet Union, Peredel'skii et al., (6) found that a dose of 5,000 r of X-rays applied to food grains infested with weevils (Calandra oryzae L.) at any stage of development was very close to the minimum sterilizing dose. They further suggest that doses of 8,000-10,000 rad may possibly be adequate to sterilize any type of grain and flour pest. (Later studies have shown that higher dosages are required for some insects infesting grain.) They also comment that it will be possible to use radiation sterilization on grain pests if the parameters can be provided in large-scale grain handling.

Cornwell and Morris (7) and Jefferies (8) have investigated the effect of dose on the grain and rice weevils and of dose fractionation on the radiation susceptibility of the grain weevil, respectively. At low fractionated doses, differences in survival and fertility were attributed to the recovery of somatic and reproductive cells. However, Jefferies further pointed out that fractionated treatment does not adversely affect the degree of control achieved at the commercial dose level"...because adults require the highest dose to kill and sterilize with both continuous and fractionated treatments... and with adults the level of sterility afforded by fractionated treatment is equal to that with continuous doses." Jefferies has also calculated that less than 1 in 10,000 adults of L. granarius can survive a continuous dose of 16,800 rep. This dosage has been proposed by Cornwell for the commercial deinfestation of grain effective against all stages of L. granarius. Cobalt^{60} gamma radiation was used.

In another study, Cork (9) has reported the effect of gamma radiation from Ce^{137} on the confused flour beetle (Tribolium confusum). Among other things, he observed that an irradiation of 20,000 r or greater produced complete annihilation of all subgroups within 20 days. No mention of sterility effects was made.

5. Use of sterile male techniques for residual protection

One of the most successful biological uses of nuclear radiations has been the classical case of eradicating the screwworm in the Southeastern United States and on the island of Curacao by releasing male flies made sterile by gamma radiation.

In attacking the problem of screwworm eradication, it was found in laboratory tests that a dose of 3 krep caused complete sterility in male flies but left them with normal sexual behavior. Experimental mating of a number of flies in cages showed that the female mates only once and, if this mating is with a sterile male, the eggs laid are sterile. Also, the caged matings showed that the percentage of sterile eggs was almost directly proportional to the percentage of sterile males in the cage. This shows the possibility of decreasing the population of this insect if enough sterile males can be released in a given area. Table 2 (Ref. 3, p. 343) shows the mathematical result of releasing, at four different periods, a number of sterile males equal to twice the original natural population of males. Theoretically such a procedure would eliminate the population.

Cornwell (10) has reported on the use of the sterile male technique for residual control of insects infesting grain. The reproductive potential of insects which survive sublethal doses of insecticide was unaffected by the treatment, but substerilizing doses of ionizing radiations (10,000-12,000 rads) caused deleterious effects in the gametes which kept the suppressed population to a low level for many months. Irradiation with 6,000 rads (40% of the evaluated dose) results in 10 percent survival at 3 weeks and 3 percent at 4 months after treatment; fertility is reduced to 0.6 percent.

The reproductive potential of insects treated at 6,000 rads (40% of the evaluated dose) is further reduced to one-third when 20 percent of the insects are treated at 16,000 rads. Underdosing with 10,000 or 12,000 rads could probably be tolerated to an even greater proportion of the product without loss in efficacy.

The relative merits of toxic chemicals and sterile sperm may be compared. Fumigation of grain <u>in situ</u> in bins or boat holds may also control the resident population of insects in the fabric of the bin or hold. The product, however, is in no way protected when handled for transit or storage. Irradiation provides partial protection to treated grain through the insemination of contaminants with sterile sperm. The degree of protection is greater with treatment below the evaluated dose (in the presence of low residual survival) than with the "minimum effective" dose. At 16,000 rads, sterile sperm once inseminated remains competitive with fertile sperm subsequently introduced, for a period of at least 4 months, although all sterile adults die 3 weeks after irradiation. Irradiation thus affords some measure of protection during the handling of grain for storage or shipment.

Attempts to induce resistance to ionizing radiations in the grain weevil have so far failed. Vigor tolerance to fumigants and resistance to contact insecticides can adversely affect the efficacy of conventional methods of control.

6. The influence of attenuation and geometry on uniformity of the radiation dose received

As gamma radiation passes through wheat and wheat products, there is an attenuation of the initial radiation flux. At any absorber depth x, the rate at which the number of photons decreases will be directly proportional to the attenuation coefficient and to the number of photons present, or

$$\frac{dI}{dx} = -\mu I \qquad (1)$$

Integrating (for a homogeneous absorber)

$$I = I_o e^{-\mu x} \qquad (2)$$

where I_o = intensity of gamma radiation at surface, roentgens per hour

I = intensity of gamma radiation at distance x, roentgens per hour

x = absorber thickness, centimeters

μ = linear attenuation coefficient, reciprocal centimeters

Instead of using absorption coefficients, it is often more convenient to express the absorption in terms of half-value layers or tenth-value layers. A half-value layer is the thickness of an absorber that will transmit one-half of the radiation beam. The following relationships exist:

$$\text{half-value thickness, } t_{1/2} = 0.693/u \qquad (3)$$

$$I = \frac{I_o}{2^n} \qquad (4)$$

where n = number of half-value thicknesses

μ = linear absorption coefficient

Some half-value thicknesses (broad beam) of different foods have been determined at The University of Michigan. Figure 3 shows half-value thicknesses for bulk wheat and bulk wheat flour. In these observations about 9 inches of bulk wheat were required to reduce the radiation intensity to one-half its initial value.

In addition to attenuation of radiation, the radiation source poses a problem. The simplest geometry is that of a point radiation source. The radiation field in the space about this source varies inversely with the square of the distance from the point source to the location of radiation. For example, if we have a bag of wheat that is 2 feet in width with the nearer side located 2 feet from a point source and the far side located 4 feet from the same point source, the nearer side would receive four times the radiation dosage as the far side for the same exposure time without consideration of attenuation. With a source having an effective shape of a rod of infinite length, the radiation field varies inversely as the first power of the distance. With a cylindrical source, the radiation is essentially uniform across a plane perpendicular to the axis of the source and within the cylinder. Thus the geometry of a cylinder source is much better than that of a rod or point source in regard to uniformity of the radiation field. For this reason, many experimental gamma radiation sources have been made in the form of hollow cylinders. However, for commercial use the hollow cylinder is not very economical if only the radiation field within the cylinder is used. Thus other geometries, such as a matrix of rod sources of simulated plaques, considerable engineering judgment, and a certain amount of compromise are required in selecting the best geometry for the radiation course of a particular practical application. In any compromise there will be some lack of uniformity of the radiation field.

Thus because of attenuation of the radiation, and variation of the radiation field because of geometry, a nonuniformity in exposure can be anticipated. In the case of wheat (having a half-value thickness of about 9 inches for Co^{60} gamma radiation) handled in 100-lb. bags, we must anticipate a maximum to minimum dosage ratio of about 2.0 from attenuation alone. This would indicate that the wheat nearest the source would receive a 40,000 rad dose to maintain a minimum of 20,000 rads in the center of the bag using exposure from both sides. We must allow some additional variation to compensate for geometry. We believe that with good engineering design the maximum exposure can be limited to 50,000 rad while assuring a minimum exposure of 20,000 rad. This maximum limit of 50,000 rad also is consistent with the objective of maintaining good baking characteristics in irradiated wheat flour.

7. Proposed label

INSECT-FREE GAMMA PROCESSED WHEAT
(Not suitable for use as seed)

HOLD IN INSECT-PROOF CONTAINERS

NAME OF PROCESSOR_____

DATE OF TREATMENT AND PLACE_____

EXPOSURE 20,000 - 50,000 rad

8. Conclusion

All evidence to date indicates that a dose of 20,000 rad will break the reproductive cycle of insects infesting wheat and wheat products. Some insects require only 5,000 rad whereas others may require up to about 16,000 rad. The dose of 20,000 rad minimum thus provides a minimum factor of safety of about 15 percent and a maximum factor of about 400 percent.

By lowering the dosage to about 10,000 rad (or less with certain insects), adult survivors are sexually sterile. By maintaining a controlled number of adult sterile males in the grain, reinfestation from outside by fertile females can be controlled.

The maximum dosage of 50,000 rad is necessary in any practical commercial gamma irradiator to allow for attenuation of the gamma field by absorption of gamma radiation by the wheat or wheat products. Another factor necessitating an allowance for overdosage is the lack of complete uniformity of the radiation field using a practical design for a gamma irradiator. No detrimental effects of a dose of 50,000 rad have been observed with irradiated wheat and wheat products in regard to nutritional value, wholesomeness, and quality of products made from irradiated wheat flours. In fact, some investigators have reported beneficial effects in the quality of bread made from irradiated flour receiving dosage from 25,000 to 50,000 rad.

D. Practical Methods of Use of Gamma Radiation with Wheat

1. Unique quality of 100-percent sterilization using gamma radiation

The nature of gamma radiation makes possible penetration to every interstice in the grain being irradiated and the treatment of every insect and insect egg even though the eggs are in concealed and confined locations. This is not possible with chemical toxins used as fumigants because, in this process, we must depend upon diffusion of the poisonous gas through the grain, past any barrier between the gas passages and the egg and finally through the membrane shell of the egg itself to produce its lethal effect. This unique quality of 100-percent sterilization has been overlooked by many who have considered the feasibility of insect control by gamma radiation.

Different fumigants have different prices and the cost of treatment varies depending upon the fumigant, method of treatment, and whether or not the grain is turned at the time of fumigation. Cost figures provided by the largest handlers of grain in the U. S. indicate that cost for chemical toxins used alone vary from a low of about 0.1 cent per bushel to 0.6 cent per bushel. The cost of labor for addition of the fumigant is negligible when it is added at the time of filling a grain elevator. If the grain must be turned during storage and retreated, the added cost is about 1 cent per bushel.

In comparison, the minimum cost for treatment with gamma radiation has been estimated at about 1/2-cent per bushel and may be 2 cents per bushel or more if the radiation facility is not used efficiently (11). Thus, on a single-treatment basis and price only, the process of treatment with gamma radiation cannot compete with the use of fumigants. However, the use of poisons in food for insect control involves certain hazards well known to the Food and Drug Administration. The elimination of this practice where possible has a value in terms of greater safety.

The greatest value that gamma irradiation has in the handling of bulk wheat arises when the grain must be turned and fumigated two or more times during storage. These instances are not common in northern United States and in northern Europe, but occur frequently in the tropics. In warm climates the reproduction of insects is more rapid and treatment three or more times per year may be required using toxic fumigants. In such cases, a single treatment with gamma radiation followed by storage in insect-proof containers could be more economical and more satisfactory. If treated with gamma radiation and stored in insect-proof steel elevators which are ventilated with control of temperature and humidity, large quantities of grain might be stored for indefinite periods of time in warm and tropical climates - an entirely new concept in grain storage in such areas.

For wheat products such as flour, meals, pancake mixes, etc., irradiation of the packaged product would guarantee destruction of all insect eggs. Although insect eggs usually can be removed from fine white flours by bolting and screening operations, this may not be possible with coarser products in which the size of the cereal particles may be larger than the insect eggs.

2. Use of insect-proof containers

The advantage gained by 100-percent sterilization may be lost if the irradiated wheat or wheat products are not stored in insect-proof containers so as to prevent reinfestation after irradiation.

Welded steel cylinders with conical bottoms having capacities comparable to present reinforced concrete elevators might be used for storage of irradiated wheat or wheat products. Such vessels would have no cracks or crevices where insects and insect eggs might escape and hide. Ventilating ducts would be screened and protected to prevent entry of insects. A typical storage vessel might be 20 feet in diameter and 150 feet high with a shell thickness of 1/2 inch at the top and 7/8 inch at the bottom.

Wheat products such as cake flour mixes, pancake mixes, biscuit mixes, etc. are usually packaged in rectangular cardboard boxes. If these boxes were coated with a plastic film containing small amounts of an insect repellant, the box might be made insect-proof. An additional film of aluminum foil should be placed between the plastic and the box to prevent insect

repellant from diffusing into the box and to prevent the odor of the wheat products from diffusing outward, thereby attracting insects. Metal containers such as "cans" of suitable size and glass jars might be used with tight covers as another form of insect-proof containers.

Horne and Brownell (11) have described the possible use of another method which might be suitable for use with U. S. wheat shipped to India. The procedure proposed involves sealing the grain within specially prepared insect- and water-proof bags containing from 50 to 100 pounds of grain a piece. The bags of grain would then be irradiated with doses sufficient to sterilize biologically the insects and the eggs contained in the grain. The bags of grain could then be stored indefinitely or transported great distances with no danger of spoilage. The bags need not be opened until the grain is ready to be used at mills or as food for humans or farm animals.

To be suitable for use in the process described above, the bag should be made of material which is impermeable to water vapor and permeable to atmospheric gases. The impermeability to water vapor protects the grain from moisture, thus preventing swelling and spoilage. Permeability to atmospheric gases is beneficial since the grain during storage and shipment will give off carbon dioxide and other gases which must be able to pass through the bag to the atmosphere. Otherwise, the bag might rupture and the grain be lost.

One proposed bag-arrangement would utilize any ordinary bag used for grain treated with a suitable insecticide and provided with a polyethylene liner. The liner could be coated on the inside surface of the bag or be a separate bag within a bag. Polyethylene film might be used as the liner since it is heat-sealable, easily providing the necessary protection against the admittance of water and water vapors. However, any material having the properties of polyethylene would be suitable. Polymylar, for example, would have the additional advantage of forming a barrier to the transfer of odors and other undesirable external conditions.

The Indian scientists Pingale, Majunder, et al., have reported success in the use of lindane-impregnated jute bags for insect proofing. They report that the quantity of lindane (19.2% gamma-BHC) required to impregnate bags is so small that there is no risk of contaminating foodstuffs stored in the bags. They also state that washing impregnated bags with water did not remove the lindane.

The storage-life of grain in such bags might be extended appreciably by use of a polyethylene liner and gamma irradiation. Once the grain has been placed in the bags and irradiated, it would not be necessary to store the bags within a grain elevator or the like. Rather, the bags could be arranged on the ground in the open air, with only some slight protection between the bags and the ground, and covered to prevent the accumulation of undue moisture.

It is conceivable that such a process as that described could solve some of the major problems involved in shipping bulk or bagged grain to India and to countries which have little or no grain-storage facilities. The grain stored in the insect- and water-proof plastic-lined bags might be left in the open in these countries with only a tarpaulin for cover, without adverse effect. To facilitate transport they might even be floated in groups on a raft along rivers and waterways.

The cost of such special bags would add a capital cost to grain storage. This could be minimized by using the bags again for, perhaps, four or five shipments and storings. Since grain stored in such containers would not need fumigation or storage in elevators for protection against weather, savings could be realized which could offset the cost of the new containers.

3. Designs and economics for stationary gamma-irradiators

Horne and Brownell (11) have reviewed some designs for irradiators suitable for processing wheat and wheat products. The design of a production facility has to cope with two major groups of problems: (1) What shape and size of source arrangement should be used to provide the maximum of usable radiation-energy with a minimum absorbed in the source itself? (2) How may a conveyor system be arranged around the radioactive source so that maximum absorption of radiation is achieved without overexposure of parts of the product and without holding up an unduly large volume of product in the facility?

Figure 4 illustrates the principles involved (11). It shows a flour irradiator which might be situated in the basement of a large mill. The facility would become an integral part of the manufacturing operation and would be so located that the bagged flour could be conveyed to the entrance of the chamber, placed in a bucket conveyor and transported into, through and out of the radiation field. The bags could then be conveyed to a shipping or storage area. The bucket conveyor is shown passing through an opening in the floor to the access passageway of the chamber. Along this, it makes a series of 90 degree turns (incorporated to prevent the escape of radiation) and continues on into the radiation cell. Here it passes under, up, and over the radiation source and leaves the cell via the access passage. For whole grain irradiation, it would be desirable to irradiate in bulk.

A design for a low-cost gravity-flow irradiator was developed by the Curtiss-Wright Corporation (11). In this design (see Figure 5) a bulk-flowing food such as grain would pass by gravity through the irradiator at the top of a storage elevator. This eliminates the cost of additional conveyor-equipment. The use of a compact vertical duct for the radiation chamber greatly reduces the cost for shielding. Control of the dosage is obtained by an adjustable orifice at the bottom of the radiation chamber.

One of the chief design factors taken into consideration here is the method of positioning the radiation sources to maximize the absorption of the radiation with minimum overdosage. In an early analysis of the use of a Co^{60} rod-source for food irradiation, it was shown that if a 3-pound commercial can of food was rotated adjacent to a single-rod source, the dosage on the surface of the food would be about 10 times that received in the interior. The inefficiency in this respect of a single-rod source is exceeded only by a point source. If multiple-rod sources are used, the uniformity can be increased greatly. For example, if 10 rods were placed around the can of food instead of rotating the food adjacent to a single rod, the activity in each rod might be reduced by a factor of 10 to maintain the same total activity, and the radiation flux between rods would be essentially uniform. The reduction of local overdosage approaches 10 for the example above, depending upon the size of the sample, the distance between sample and source, the energy of the gamma-source, and the absorption coefficient of the sample. Thus, by using a number of rod sources, an essentially uniform radiation field can be obtained without penalty from the inverse-square law.

To utilize the maximum amount of the radiation, a single cylinder of food should not be irradiated by a circle of rods, since all the radiation outward is lost in the shield around the source and since much of the radiation inward may pass through the food into the shield. Instead, a matrix of sources and food should be used with a width the value of several half-thicknesses to permit maximum absorption of the gamma radiation in the food. This minimizes the radiation lost at the edges to the shield.

The ideas described above were incorporated in the Curtiss-Wright design which was optimized by performing the necessary calculations on an IBM-704 machine. Figure 5 is a sectional view of a Curtiss-Wright experimental-size, continuous-flow grain irradiator. This design is for a portable unit utilizing lead shielding. If installation in a grain silo is desired, the shielding could be ordinary concrete and the size would be larger. Grain or other granular or liquid materials enter through the top labyrinth, flow downward by gravity past the distributed array of axial rod sources and leave through the lower labyrinth and flow-control throttle. The flow chamber, and source dimensions and geometrical arrangement can be varied to suit the material being irradiated and the isotope to be used. Essential specifications for the wheat configuration are shown in Figure 5.

To explore the economic feasibility of the gravity-flow irradiator, a cost breakdown and capacity calculation can be made to provide an estimate of the cost per bushel of irradiating grain with a dose of 10,000 rad. This estimate indicates the cost per bushel for disinfestation of wheat by irradiation to be in the same range as that for chemical disinfestation. The exact cost depends, of course, on the assumed price of the cobalt. Using a current price of $1.00 per c, the cost is about 0.5 cent per bushel for 24 h/d operation.

An alternative is to use an irradiator consisting of a series of concentric cylinders, such as described by Cornwell. This facility consists of

a source contained in a cylinder, diameter 8 inches and length 10 feet, surrounded by a cylinder of 2 feet in diameter. With the annulus so formed, surrounding the source with two further cylinders to provide outer annuli with capacities of 56 and 84 cubic feet, respectively, the flow rate could be increased to 25-30 t/h and the efficiency of the system to around 40 percent. This would require approximately 21,000 c for a dose of 20,000 rad.

Brownell (3) has reviewed studies on the optimal location for a radiation source for grain elevator operations as well as the economics of the operation. The study on optimal location was based on the assumption that a minimum of plant space, capital investment, or product price increase should be available or tolerated. However, because of the heavy shielding required, a better location for the irradiator might be at or below grade level directly beneath the hopper weight scale (see Figure 6). Placing the irradiator below grade level would permit the use of earth for some of the shielding, and gravity flow could be used from the hopper weight scale through the irradiator. To prevent reinfestation of the treated grain, the conveyor, elevator, and storage bin should be constructed so as to be insect-proof after receiving irradiated grain.

The economics of irradiation of grain with Co^{60} have been analyzed by Chamberlain (3). Assuming that the equipment operates 100 days per year and that irradiation charge is 1 cent per bushel, he reported potential income as shown by the heavy straight line in Figure 7. The other lines represent the cost of the irradiator. The vertical distance between the two lines gives the potential annual profit.

4. Designs and economics for mobile gamma irradiators

If there is a seasonal variation in the capacity requirements for irradiation of wheat, mobile irradiators may be used to advantage so as to avoid high investment costs during periods of low demand. For example, at the IAEA panel meeting held in Vienna, May 21-24, 1962, on disinfestation of grain, a variable capacity of 4 to 200 tons per hour was specified. If the same gamma facility designed to handle 200 tons per hour was used at 4 tons per hour, the unit charges for radiation processing would be increased by a factor of 50. Thus if the costs were 0.5 cent per bushel at 200 tons per hour capacity, they would be increased to 25 cents per bushel at 4 tons per hour.

Actually 4 tons per hour is not a realistic value for the unloading transfer and filling of storage facilities. Such a low handling capacity would be used only for a process plant such as a flour mill. In the U. S., grain is handled by commercial operators at capacities of 150 to 350 tons per hour and in few locations at 600 tons per hour. Thus the capacity of 200 tons per hour is realistic for commercial unloading practice.

Brownell and Horne (12) have proposed the use of a ship containing a gamma source as a mobile irradiator. Such a ship would be stationed in a port receiving grain and would irradiate grain as it was unloaded. Horne (13) has described such a ship and discussed costs assuming some governmental support.

A Liberty Ship from the U. S. mothballed fleet makes an ideal grain handling and irradiation facility. Figures 8 and 9 show how easily the compact nuclear irradiation system fits into Hold No. 3. Note the ample space for storage. After mooring anywhere in the world, the ship will be ready to receive grain.

The grain will be bagged in insect-proof jute sacks. These bags, specially impregnated with lindane, are an effective reinfestation barrier for many months. The filled bags of treated grain are easily brought ashore even in harbors with minimal facilities for both unloading and storage. The ship can then move on to the next destination.

The ship's crew would be professional seamen. The operators and scientists for the radiation treatment program can be drawn from Peace Corps volunteers. This program provides another important opportunity to demonstrate practical assistance to other countries. The unloading of bagged grain would be done by local labor.

The source itself would consist of 130 elements of 6,000 curies each, making a total of 780,000 curies. This arrangement is similar to the system Curtiss-Wright has designed for the U. S. Army Q.M. Corps Food Process Development Irradiator. The elements will be arranged side-by-side in a plaque 11 feet long by 12 inches high and 1-1/2 inches thick. Estimates of costs for preparing and operating the ship are given in Tables 3 and 4, respectively.

It is estimated that a source of this size could treat 9-10,000 tons of grain (the amount carried in an average cargo vessel) in a 1-week period or 80 tons per hour based on 120 hours per week of operation. The grain could be transshipped into the storage holds of the "Grain Ship" in 2 days, thus ensuring a rapid turnaround for the cargo vessel. Three ships would be required to handle 200 tons per hour capacity.

When not irradiating grain, the source is housed in a lead storage castle 13 feet long by 2 feet 3 inches wide and 3 feet high, weighing approximately 29 tons. The source is fastened to the underside of the castle lid and is lifted and lowered with the lid. The weight of the lid and source is 1,600 pounds. It is manipulated with a cable hoist and guide rail system. The source would be initially loaded into the storage castle by remote manipulation in a hot cell and safely transported and installed in the ship. A shield of sea water is used to surround the radiation cell.

A summary of the estimated waste reduction and resultant savings is given in Table 5 .

TABLE 3.--Cost for preparing a grain ship

In the cost studies, the assumption was made that the basic Liberty Ship will be made available from the Government at no cost. Therefore, for this purpose, the costs considered were only that of demothballing the Liberty Ship, converting Hold No. 3 to receive the radiation unit, converting the remaining holds for grain storage and installing bagging and conveyor equipment:		$350,000
The assumption was also made that the initial Co^{60} loading would be a grant from the U. S. Atomic Energy Commission. Estimated cost for the Co^{60} storage cask, operating equipment, and all necessary instrumentation and controls:	$150,000	
Cobalt source fabrication	50,000	
Contingency for unanticipated expenses:	100,000	
		300,000
		$650,000
		(the equivalent of 250 automobiles)

TABLE 4.--Annual cost for operating a grain ship

Salaries for ship crew and radiation scientists (25 persons - average salary $10,000)	$250,000	
Operation and maintenance expenses	300,000	
Depreciation of Co^{60} from radioactive decay	160,000	
Miscellaneous	50,000	
		$760,000

Such a ship operating in a tropical country can provide annual savings of $3,990,000 which would feed an additional 375,000 people for a whole year.

TABLE 5.--Summary of waste reduction and resultant savings
(based on one operating grain ship)

Where the loss to insects has been 1 out of 4 tons or 25%, each ship will make possible a savings of $3,990,000 a year.

Where the loss has been 1 out of 8 tons or 12-1/2%, there will be a possible savings of $1,290,000 a year.

Here are the figures:

	If insect loss was 25%	If insect loss was 12-1/2%
(1) Cost to U. S. for grain shipped abroad is $60 a ton. Each ship can annually handle 40 cargoes of 9,000 tons/yr. for a total value of:	$21,600,000	$21,600,000
(2) Insect loss:	$ 5,400,000	$ 2,700,000
(3) Irradiation will decrease insect damage to a maximum of 3%--resultant loss now only:	650,000	650,000
SAVINGS	$4,750,000	$ 2,050,000
Cost of operating ship:	760,000	760,000
YEARLY SAVINGS	$3,990,000	$ 1,290,000

One ship will save enough food to feed 375,000* additional human beings per year with the same initial grain.

It is appreciated that the pure economics of grain irradiation are even more favorable for a fixed irradiator built at a single site such as a major port. However, the mobility of a ship has the advantage that its benefits may be brought in succession to the people of a series of countries. In this way, U. S. help may be more widely demonstrated and appreciated.

* Based on a 25% loss situation.

Another type of mobile irradiator could be in the form of a railway car containing a gamma source in a steel-shielded room as shown in Figure 10. The use of steel for shielding rather than sea water and the smaller size of the conveyor would increase the unit costs of irradiation slightly as compared to those for the ship irradiator. However, an irradiator on rails could process grain in inland areas wherever there are suitable rail connections and where a water-borne irradiator could not be used.

In more remote areas an irradiator might be carried in a motor truck. A schematic design for such an irradiator is shown in Figure 11. This design is for a portable potato-irradiator built in Canada and used for potato irradiation (Co^{60} gammas) of 1,000,000 pounds of potatoes in 1961. The unit irradiation costs will be high because of the large reduction in capacity. Therefore the use of such a mobile irradiator probably would be limited to demonstrations of the process and other special applications.

5. Measurement of dosage delivered

The chemical changes brought about in wheat or wheat products by irradiation are so minute as to be below the reliable limit of chemical analysis. It is therefore necessary to control the use of low-dose irradiation by controlling the process itself. Then, knowing the particular installation in which the process is carried out, it is possible to calculate and verify by measurement the actual dose rate at different points in the path taken by the food through the irradiation field. By integrating with respect to time, it is then possible to obtain a figure for the total radiation exposure of the food.

In operation, the radiation exposure of the food at all points in the container (bag or package) may be determined by placing glass, chemical, or other dosimeters at all such points in the container. This dosimeter container is then passed through the installation and is exposed to the radiation field in the regular manner. Examination of the exposed dosimeters will then show clearly the extent of the irradiation exposure, including its maximum and minimum values for that particular container. The emission of gamma photons from a radioisotopic source is essentially a continuous and certainly predictable phenomenon. The dose received by any container exposed in a similar manner to the irradiation field must receive a similar irradiation exposure, due allowance being made for the natural rate of decay in radioactivity of the source.

Thus in an installation consisting of a source of radiation and a conveyor for exposing food to the radiation, the dose received by each food container may be controlled by controlling the speed of the conveyor.

It is proposed that the irradiation exposure of the food be determined using chemical or other approved dosimeters in selected containers and that this exposure be controlled by regulating the speed through the irradiation field of the conveyor.

The details of the irradiation process will be recorded on the label in the manner shown (see C.7).

6. Conclusions

For a single treatment the use of gamma radiation will be more expensive than the use of fumigants, probably by a factor of 2 or more. However, if more than two fumigations are required during storage of the grain, the irradiation process could be the more economical as a single irradiation will suffice if the treated grain is protected against reinfestation.

Insect-proof elevators of welded steel construction, cardboard cartons and bags with specially treated surfaces, cans, and jars can provide protection against reinfestation.

Cobalt^{60} probably will be more economical as a gamma source than Ce^{137} if the period of amortization is 5 years or less. For longer periods of amortization Ce^{137} probably will be more economical.

The geometry of the source is an important consideration in obtaining efficient use of the radiation sources and in keeping the dosage range between 20,000 and 50,000 rads. The gravity-flow irradiator with a matrix of rod sources has an advantage for processing loose grain. The simulated plaque source has an advantage for the irradiation of bagged wheat and packaged wheat products.

If the irradiation capacity is seasonal and varies widely such as 4 to 200 tons per hour mobile irradiators may be used in numbers sufficient to meet the demand. Irradiators could be used on shipboard for this purpose to treat grain on entry through a seaport. Appreciable quantities of wheat lost to insects in the tropics might be saved by this technique.

For continuous processing at fairly uniform rates, permanent irradiators would be preferred, possibly using the gravity flow design for loose grain and a bucket conveyor for bagged grain and packaged wheat products.

Radiation dosages can be calculated as the integral of dose rate with respect to time of exposure and verified by use of chemical and glass dosimeters.

ACKNOWLEDGMENTS

I am deeply indebted to many for assistance which made possible the preparation of the wheat petition approved by the Food and Drug Administration.

Thanks is given to the Michigan Memorial Phoenix Project and its many contributors for support of the original feeding experiments using irradiated whole wheat. These experiments and 12 years of associated research provided the basis for the petition. I thank the U. S. Army Quartermaster Corps and U. S. Army Office of the Surgeon General for permission to use data obtained under Army contracts in preparation of the petition. I thank the General Foods Corporation for the Grant-in-aid made to the University to study irradiated foods under my supervision. No official support or approval from any governmental agency, corporation, or the University was given to prepare the petition. Only by the availability of unrestricted funds from the General Foods Company grant, could the incidental costs for preparing the petition such as typing, employment of student assistants, and reproduction be met.

Thanks is also given to Professor Wiant of Michigan State University, Dr. Josephson of Natick Laboratories and Dr. Sanielevici of IAEA and many in AEC for assisting in obtaining supporting data on the baking quality of irradiated wheat flour. Many others have assisted in other ways whose names are not included but whose assistance has been appreciated.

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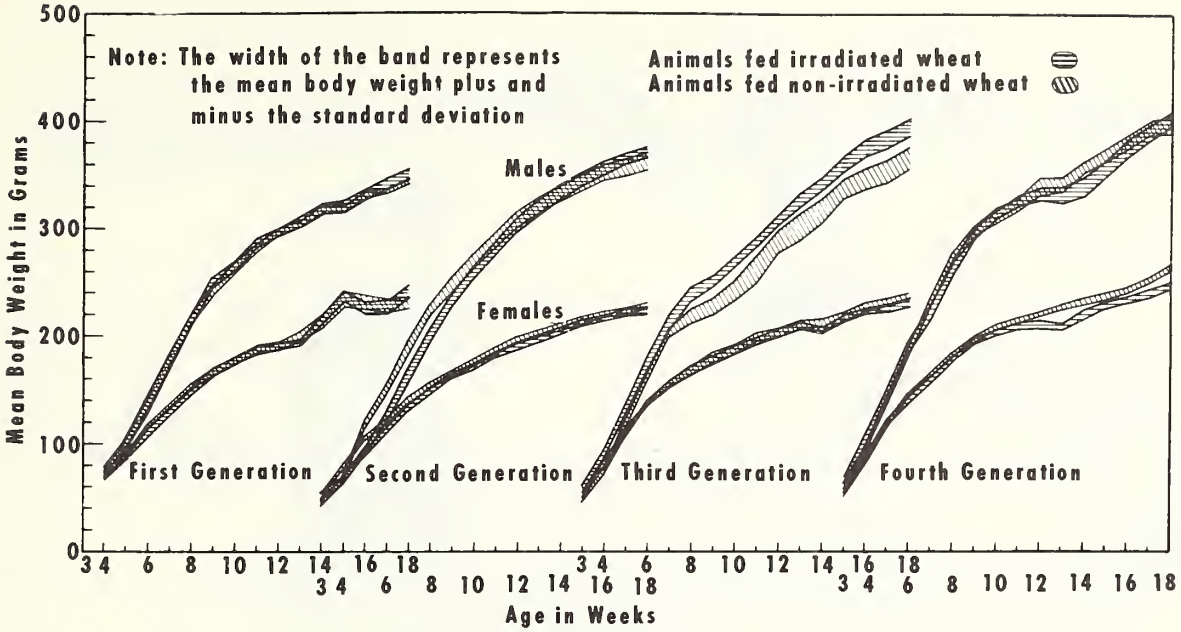

Fig. 1 Growth rates of four generations of male and female rats fed irradiated and nonirradiated wheat.

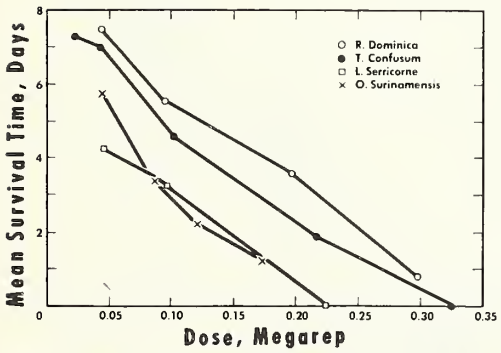

Fig. 2 Effect of gamma radiation on mean survival time for adults of four insect species (Ref. 3, p.272).

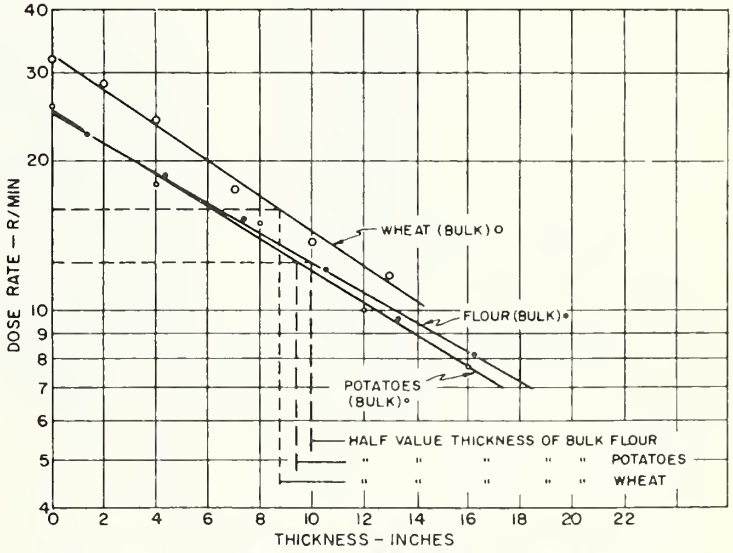

Fig. 3 "Broad-beam" absorption measurements showing "half-value thickness" of three foods (measured in the radiation cave, Fission Products Laboratory The University of Michigan).

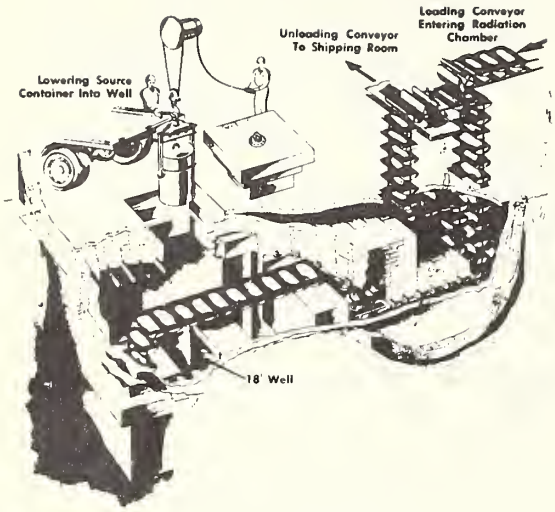

Fig. 4 Schematic arrangement of irradiator for bags of grain, situated in basement of existing mill.(11)

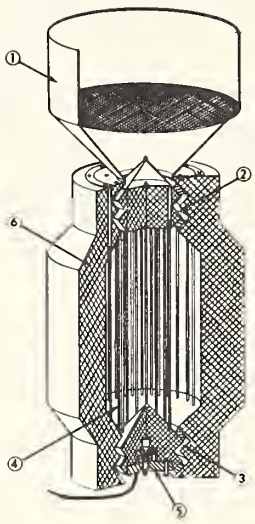

Fig. 5 Sectional view of gravity-flow irradiator: 15,000-curie Co^{60} gamma ray source, capacity

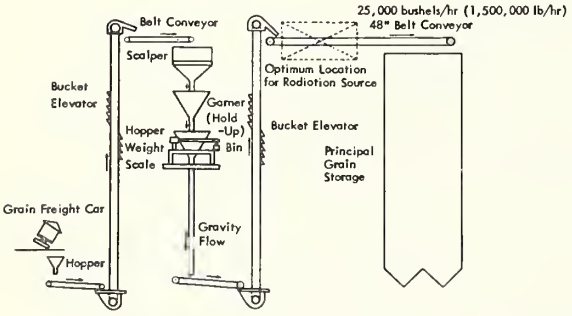

Fig. 6 Flow diagram for grain elevator operations.(3)

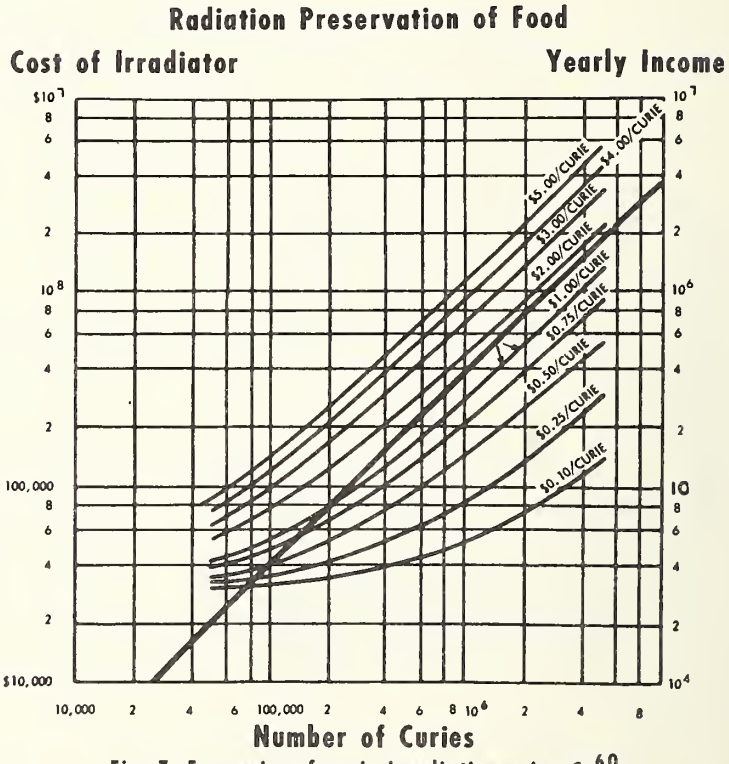

Fig. 7 Economics of grain irradiation using Co^{60}.

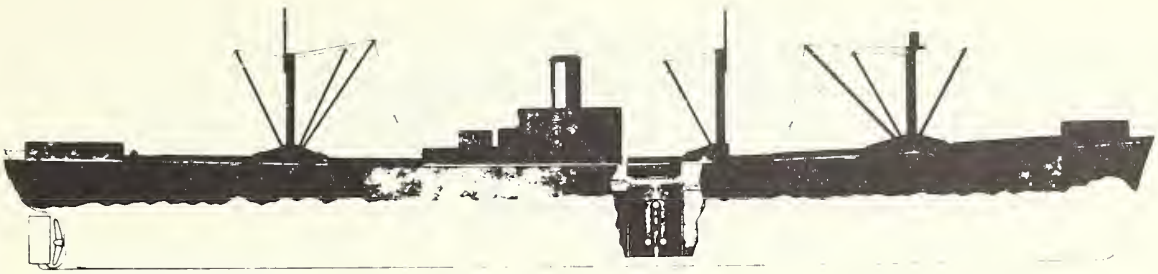

Fig. 8 Grain irradiation installation in single screw cargo vessel (Princeton Division, Curtiss-Wright Corporation).

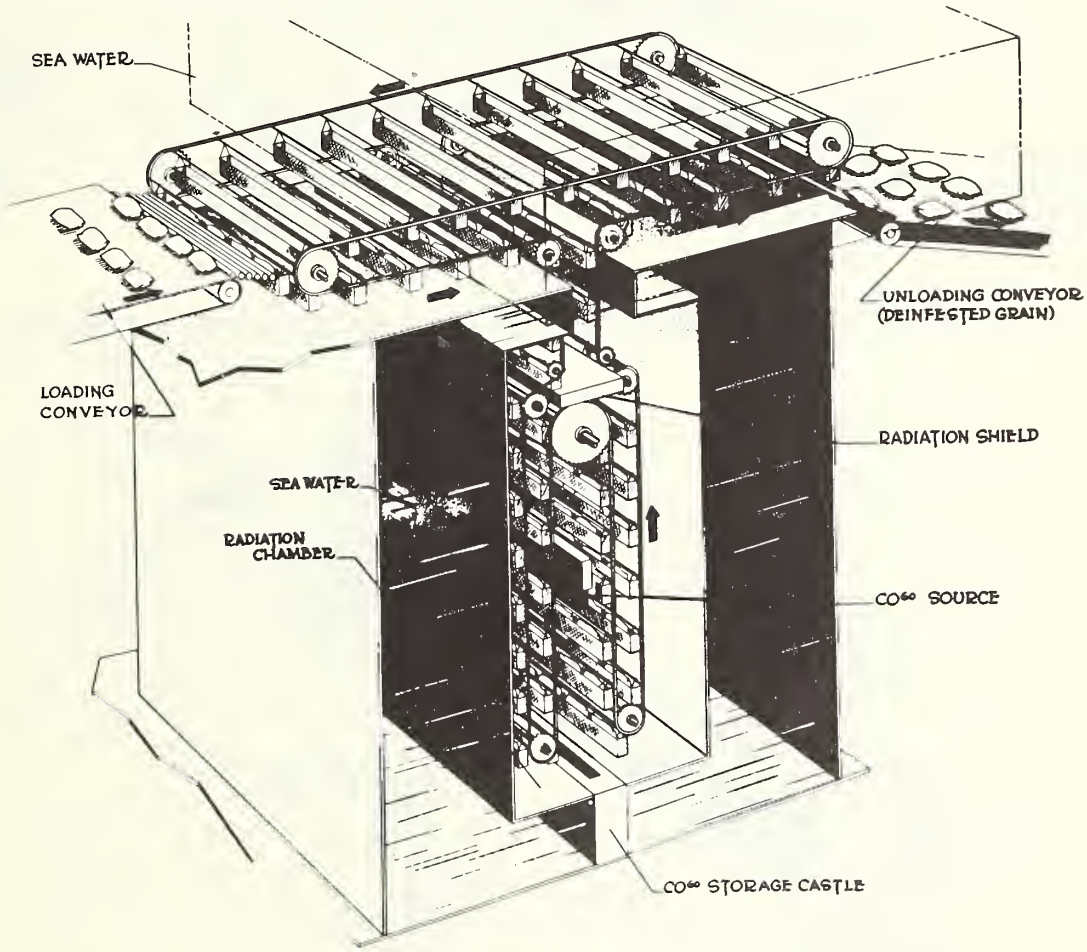

Fig. 9 Grain irradiation installation in single screw cargo vessel (Princeton Division, Curtiss-Wright Corporation).

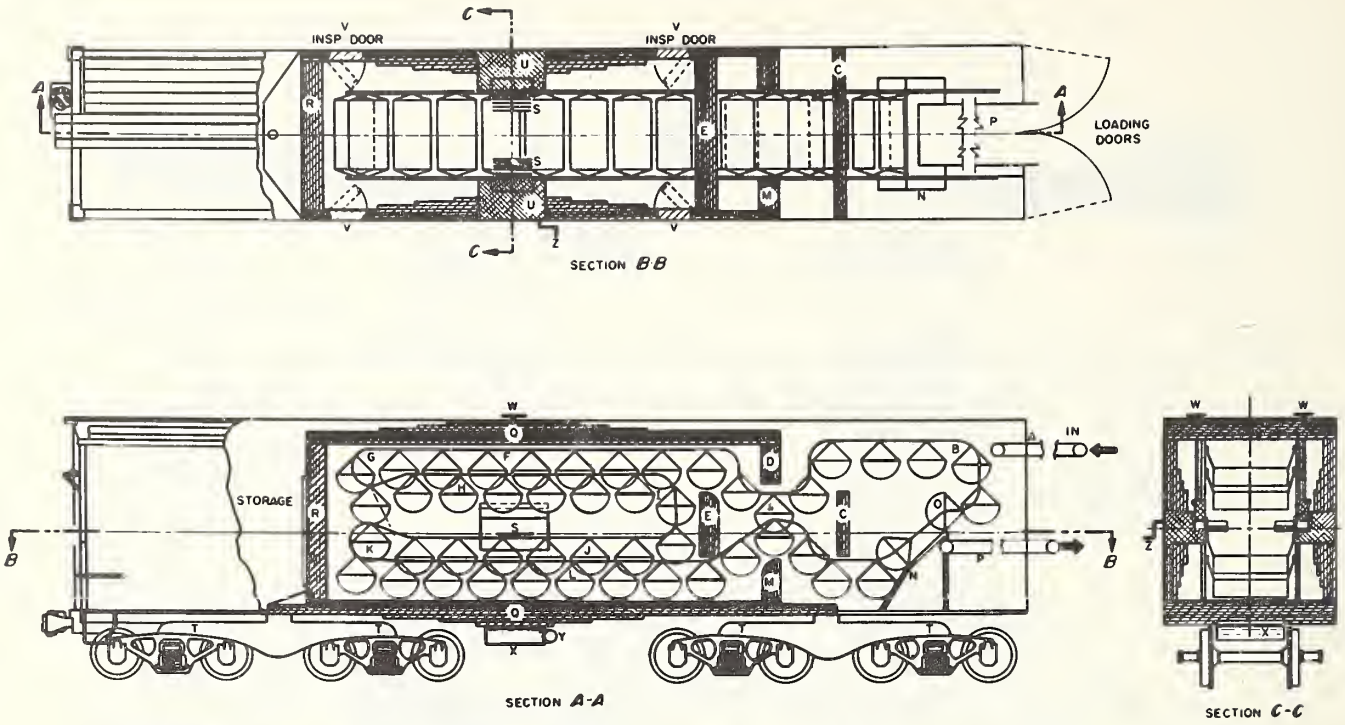

Fig. 10 Plan, elevation, and end sectional views of railway mobile irradiation facility.[1]

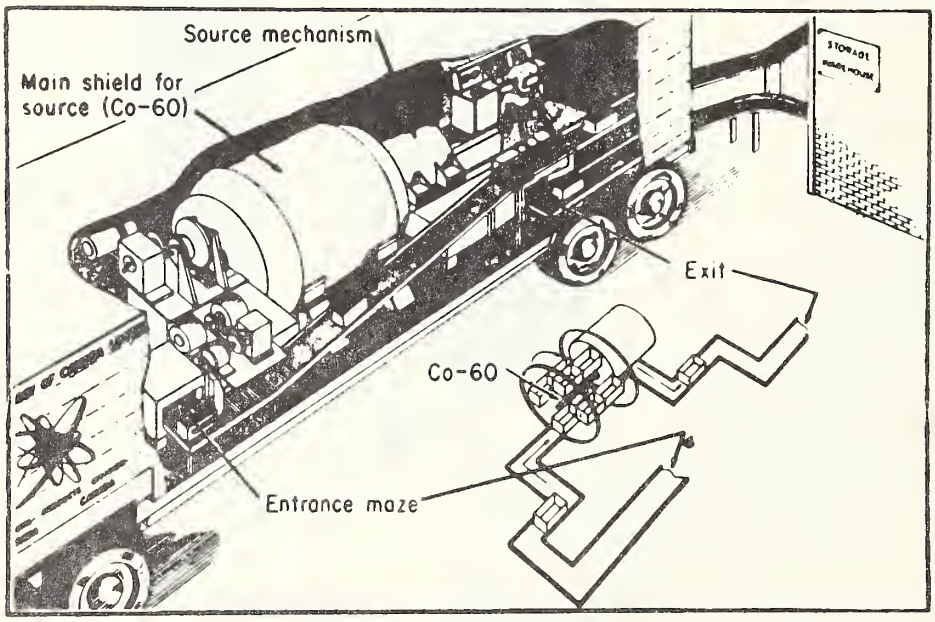

Fig. 11 Diagram of irradiator shows buckets of potatoes being processed. Small sketch (lower right) shows "ferris-wheel" rotation around Co^{60} source. AECL has been using this unit to irradiate 1,000,000 lb of Canada's 1961 crop.(14)

THE ECONOMICS OF UTILIZATION OF WHEAT FOR FOOD

Kenneth E. Ogren, Director
Marketing Economics Division, Economic Research Service,
USDA, Washington, D. C.

Costs and prices and their implications to the wheat industry is the subject matter of my talk this morning.

The first part of my discussion focuses on problems facing the industry in maintaining or increasing consumption of products. The second part discusses research studies of the economics of freezing bakery products - an innovation that appears to hold some promise for your industry.

To provide a background for this discussion, I will use an economist's stock in trade - charts.

Trends in Prices and Consumption

Bakery products, especially bread, are a major food outlet for wheat. Let's take a look at what has been happening to food in general and to bread specifically in terms of price trends.

The highlights of the data in Figures 1 to 6 may be summarized as follows:

1. General trends in food prices since 1947-49.--For the consumer, food is indeed a bargain - in price as well as in quality and in convenience. Food prices have declined relative to most other consumer prices, largely because of the decline in food prices to the farmer (Figure 1). In 1962, the farmer's return from a market basket of farm foods was 12 percent below 1947-49, while the spread between farm and retail prices was higher by 39 percent.

2. What the average trend in food prices covers up.--Let's relate the price of bread to all food prices. Prices and spreads of bread and bakery products have increased by a much larger percentage than the average for all foods (Figure 2). In contrast, retail prices and spreads for poultry and eggs and fats and oils have actually declined since 1947-49.

What are the implications of these contrasting price trends to the wheat food industry? As you know, bread has to compete with 6,000 or more items in the supermarket today for the consumer's dollar. Have additional qualities and conveniences been added to a loaf of bread to maintain or

improve its competitive situation? We have been told that lowering the price of bread will not increase consumption. But, what effect will an increase in bread prices have upon sales and profits to the industry?

These overall price trends suggest that bread may be at a greater disadvantage today than 15 years ago and less of a bargain to the consumer. Is this true?

3. Trends in per capita consumption.--As you know, wheat foods have not held their own in terms of per capita consumption, dropping from 194 pounds in 1947-49 to 160 pounds (grain equivalent) in 1962.1/ How much larger will this drop be? What can be done to improve wheat's competitive position? Can anything be learned from other foods?

Price decreases, together with added quality and convenience, have resulted in a sharp increase in consumption of poultry (Figure 3). However, price declines for eggs did not result in higher consumption, but trends in consumption of potatoes in recent years are a significant story that may have important implications to the wheat industry. After all, potatoes and bread are similar in many characteristics - both in their position as important foods in the daily diet for centuries and in their declining consumption with economic development of various countries.

4. Variability in prices of bread.--Now let's go back to bread prices. The data for bread are U. S. averages that also mask much variability. For example, in the 20 large cities priced by BLS the average retail price in 1962 varied from a low of 17.4 cents in Houston to a high of 28.0 cents in Los Angeles, 61 percent higher than in Houston (Figure 4). Even more significant are the following statistics: The price of bread in Houston increased about 5 cents from 1947-49 to 1962 or about 40 percent, while the price in Los Angeles rose by 14 cents, or 100 percent. What effect has the lower prices in Houston had upon per capita consumption in relation to the higher prices in Los Angeles? It would be helpful if we knew more about these relationships.

5. What caused the rise in the average U. S. price of bread?--Primarily, the higher costs of baking and distributing bread (Figure 5). The difference between the estimated cost to the baker of all ingredients and the wholesale price rose from 6.0 cents in 1947-49 to 11.5 cents in 1962, an increase of almost 100 percent.2/ Gross spreads of millers and retailers also

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1/ For detail on domestic food use of wheat by type of product, type of wheat, and geographic distribution, see "Utilization of Wheat for Food," by H. Wayne Bitting and Robert O. Rogers, Agricultural Economics Research, April 1963.

2/ For more data on price spreads for bread, see Marketing Margins for White Bread, Misc. Pub. No. 712, U. S. Dept. of Agr., Nov. 1962. Current data on spreads for a market basket of farm foods, by commodity groups and by individual foods, are given in the Marketing and Transportation Situation.

increased during this period. But these spreads increased by a smaller amount; they also are a much smaller part of the total price of bread, especially the millers'. The price of wheat has little effect or relationship to the retail price of bread. In 1962, it would have taken a 40-percent drop in the price of wheat to lower the price of bread by 5 percent or by a single cent. Conversely, a 40-percent increase in the price of wheat in 1962 would have increased the price of bread by only 1 cent - roughly 5 percent. We have not experienced such a large change in the price of wheat in recent years.

6. Diverse trends in farm-retail spreads.--Similar to the trends in retail prices, the farm-retail spreads for bread and bakery and cereal products do not compare favorably with those for the average of all farm food products (Figure 6). The spread for bakery and cereal products has increased each year since 1947-49 for a total rise of 60 percent, while the spread for poultry and eggs has trended downward since 1951, and in 1962 was 6 percent below the 1947-49 average and 12 percent below the high point reached in 1951.

However, these data should not be interpreted to mean that wheat farmers are getting poorer and bakers are getting richer. I have not shown data that measure net profits to any group, but net profits to bakers have been declining in recent years. The price of bread has increased because the cost of the inputs - labor, wrapping materials, fuels and other supplies, and taxes have increased - not because profits have increased.

The Problems and Possible Solutions

My objective in showing you these data this morning is not to depress you with unpleasant facts but to assist us in focusing on what the problems are, what are possible solutions, and what further information and research are needed. Before giving a prescription, a diagnosis is necessary, and I believe the patient is still very much alive.

First, we need the best possible information and statistics if we are to make intelligent and meaningful analyses of the economics of the utilization of wheat for food. Incidentally, the data on farm-retail spreads provide no solutions, but whenever wheat programs and prices are in the news so are these statistics, even in the President's news conferences. With the possible uncertain price outlook for wheat next year, this public interest is not likely to diminish. Unfortunately, our data are not as accurate as we would like them to be. We invite the cooperation of the milling and baking industry to provide data that will help us improve our data.

Next, what can be done about the situation? The data in the charts suggest that a continued rise in prices and costs of wheat products is not inevitable; neither are declines in consumption. The examples set by the poultry and potato industries are indicative of the potential that lower retail prices and new convenience can achieve to increase consumption.

Since the price of wheat is a minor factor in the retail price of wheat products, lowering the price of wheat alone cannot achieve the goal. Lower prices for wheat products must be attained by reducing the cost of processing and distribution. In the poultry industry, costs of processing and distribution have decreased despite the substantial increases in the cost of their inputs, similar to those in other industries. Identification of the reasons for this success could be helpful.

In the bread industry, prices rose much less in Houston than in Los Angeles. A preliminary check on the causes of the differences between bread prices in the two cities reveals that about one-third of the difference is due to higher retail margins in Los Angeles. The remaining two-thirds of the difference may possibly be explained by differences in production costs, wholesale distribution costs, or even in demand characteristics for white bread. Further research can shed more light on these questions.

You may argue that the price of bread is not important in influencing consumption. Most analysts agree that prices of white bread have relatively little effect on its consumption, especially in areas with relatively high income levels. This, however, does not mean that the price of bread has no effect whatsoever on consumption. Not everybody is rich and certainly not everybody eats steak all the time. Furthermore, it is entirely possible that in the 25 to 30 cent price range increases in bread prices may have much greater effect on purchases than in, say, the 15 to 20 cent price range. Thus, keeping bread prices from rising further may be imperative to prevent further sharp inroads on consumption.

But white bread is not the only wheat product produced by the bakery industry. In the late 1950's, the long-term decline in per capita consumption of potatoes was halted, apparently by the introduction of several processed products. With the commercialization of potato flakes in 1958, the number of processed potato products has expanded from 10 in the mid-fifties to around 50 (mostly frozen and dehydrated) in 1963. The leveling off and subsequent slight increase in per capita consumption of potatoes has occurred because the increased use of processed potatoes has more than offset the continuing decline in the consumption of fresh.

A detailed study by our Division of the cost and time savings in the use of convenience foods showed that many bakery products fall in the category of convenience foods - mostly new products - and that some cost even less than home-prepared counterparts.3/ This is perhaps the only category of bakery products that has shown a significant rise in consumption in the past 15 years. For example, according to Census data, specialty bread shipments by the bakery industry increased from less than 200 million pounds in 1947 to 630 million pounds in 1958, a threefold increase.

3/ Comparative Costs to Consumers of Convenience Foods and Home-Prepared Foods, Mktg. Res. Rpt. No. 609, U. S. Dept. of Agr., Econ. Res. Serv., June 1963.

Today's homemakers are value-conscious, but they look also for convenience - and perhaps most important, for quality food that adds variety to their food menus. Note that the processed potato products for the most part are more expensive than using potatoes in fresh form. The development of new and convenient products by the bakery industry with improved quality, it would seem to me, could contribute significantly to expanded outlets for wheat products. And this brings me to the second part of my discussion.

The Economics of Freezing Bakery Products[4/]

Now, let's turn to our research study of the economics of freezing bakery products. Freezing, which stops yeast action in doughs and retards staling rates in baked products, permits greater flexibility in the production and distribution of perishable bakery products. Under certain conditions these changes may result in lower manufacturing and distribution costs and in products of fresher condition reaching the consumer. Both of these changes could result in increased consumption of bakery products.

From 1953 to 1961, the Department's Western Regional Research Laboratory had a continuing program of research for prescribing the optimum conditions for freezing, storing, and defrosting various bakery products. Concurrently, there was a gradual increase in the commercial application of freezing to the production and distribution of a wide range of bakery products. The growth in availability of frozen bakery products in the supermarket frozen food section is obvious even to the casual observer. It is not as widely known, however, that large quantities of bakery products are frozen in various stages of preparation, and are subsequently defrosted before being sold to the consumer.

Some of the ways in which freezing may be used in the production and marketing of bakery products are shown in Figure 7. The solid lines represent unfrozen movement; the dotted lines represent frozen movement; and the dashed lines indicate that the product may be either frozen or unfrozen. The gray boxes indicate places at which there is an alternative for temporary frozen storage.

By following the flow lines, the ways in which freezing can be used become apparent. One of the ways is to shift the proofing and baking operation, or just the baking to the consumer, restaurant operator, or branch bakery. There are several potential advantages to this use of freezing. First, it permits making up products in centralized large-scale plants, with the inherent economies of large size, then freezing them to be baked elsewhere. These products can then be baked in on-premise bakeries in supermarkets which many bakers believe results in higher sales. Availability of frozen, unbaked products also permits the institutional or restaurant

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4/ Based on a talk by Robert V. Enochian and Norman L. Rollag, Economic Research Service, Current Extent and Outlook for Freezing by the Baking Industry, February 1963.

operator to have freshly baked items more conveniently, and in many cases at lower cost, than by preparing them himself from their ingredients. Likewise, consumers have this same choice of producing freshly baked products in a way definitely more convenient than preparing them from ingredients, but less convenient than on the shelf in the retail store. The housewife can use this product by placing it directly in a greased baking pan and letting it rise for several hours before baking, or she can let the dough defrost and use it for making rolls or other bakery products. Two firms on the West Coast are now marketing frozen unproofed bread packed three loaves each in a printed polyethylene bag and selling for 49 cents for white or whole wheat and 59 cents for raisin bread. Costwise, these prices compare most favorably with the average price of bread in Los Angeles (Figure 4).

Another use of freezing is to freeze ready-to-eat products for either local distribution and sales in frozen form or for shipment to distant markets. These products may be distributed and sold frozen or may be defrosted either before distribution or at the retail level before selling. Frozen distribution permits less frequent deliveries and also reduces, if not eliminates, losses from stale products.

A possible use of freezing which we have not yet encountered would be for producing products in a low-cost location and shipping them to a high-cost location. The large price differences among cities illustrated in Figure 4 suggest this potential.

Still another use of freezing illustrated in Figure 7 is to produce each product in fixed quantities for a frozen inventory rather than attempting to adjust production to a fluctuating daily demand. This use generally results in more efficient utilization of production labor.

Survey of Bakers

We recently completed a nationwide survey to ascertain the current uses and extent of freezing to get bakers' evaluations regarding the advantages and disadvantages of freezing, and to learn their expectations regarding future uses of freezing. About 400 bakers were selected for comprehensive personal interviews. I can report some preliminary findings of our study to you today.

We found that nearly 40 percent of the bakers in the cities that we surveyed were currently freezing some of their production. The quantities frozen, the stage of production in which frozen, and the condition in which the products were distributed varied widely. Some products were found to be distributed in frozen form, but the more common practice among the bakers interviewed was to use freezing only in the production operations and to defrost frozen products before they were distributed or sold.

The use of freezing was most common among retail bakeries, both single-unit and multi-unit types (Figure 8). It is relatively unimportant among doughnut shops and multi-unit wholesale bakers.

The limited use of freezing by multi-unit wholesale bakeries is due to several factors. For one thing, most of these bakeries are large-scale operations that produce a specialized line of products--often only bread. Therefore, freezing may not result in any savings in production costs. Furthermore, even though there may be potential cost savings with frozen distribution, there are several barriers to adoption of such a system.

The Future for Frozen Bakery Products?

When bakers not now using freezing were asked if they thought they would freeze any of their production in the future, about 28 percent said yes. It is significant that of the multi-unit wholesale bakers, now among the lowest users, the percentage of yes votes was 42 percent.

Many bakers not expecting to use it in the future see no advantages to using freezing in their type of operation or believe that the quality of bakery products that have been frozen is not as good as those that have not been. Those not now using freezing who plan to in the future hope to use production labor more efficiently, and thereby save on overall production costs, and to reduce losses from staling. Such bakers now lack space for a freezer or they lack the capital for the required investment.

A majority of bakers presently using freezing may expand its use for a variety of reasons. Of the bakers presently using freezing, 55 percent said they will increase its use in the future and only 4 percent will decrease its use. Many of those who will increase its use hope to increase sales by having a wider variety and fresher quality products at lower cost than without freezing.

One of the most important factors for the continued growth in sales of frozen bakery products is the maintenance of high quality. The majority of bakers using freezing did not report any problems with or receive any complaints about products that have been frozen. However, about a third of the bakers we interviewed mentioned problems. This suggests the possible need for a program to inform bakers of the best procedures for freezing and handling frozen bakery products to assure maintenance of quality.

Another factor that we believe will be important in the future growth in the use of freezing of bakery products is its effect on costs. Most bakers using freezing said that they had achieved a net decrease in production costs. Freezing may permit less frequent deliveries to retail outlets, which may provide opportunities for considerable cost reductions by bakers through savings in labor and reductions in stale losses. These potential savings would

have to be weighed against the additional costs of installing and operating freezer equipment.

We have made a preliminary analysis of the effect of frozen distribution on wholesale bread distribution costs. Assuming that bread would be distributed as a frozen food with the same average markup and same number of deliveries per week as other frozen foods, we estimated potential net savings of 2 cents per pound loaf over the usual driver-salesman method used by most wholesale bakers today.5/ This does not include any allowance for potential savings from reduction in stale losses.

Even though distribution of frozen bakery products seems to offer potential savings in distribution costs, the competitive structure of the baking industry may inhibit the adoption of less frequent delivery. For example, the present driver-salesman system, in which each driver has daily or more frequent contact with each grocery store he serves, is directly attributable to the competition that prevails among wholesale bakers. This system enables the driver-salesman to frequently rebuild displays of his product and try to keep his brand in the most favorable display position and appearance possible. The less frequent deliveries are, of course, a key to achieving lower costs because the driver can deliver a larger quantity of bakery products in a given time period.

We also have underway a study of the comparative costs of different methods of bread distribution, in which we plan a more precise evaluation of the comparative costs of frozen distribution of bread under certain assumed conditions. If this evaluation confirms our preliminary estimate of potential savings with frozen distribution, we plan to evaluate the feasibility of adoption of a system of distribution of frozen products by wholesale bakers.

We, of course, cannot accurately forecast the amount of bakery products that will be frozen in the future. In general, bakers seem "bullish" about its potential. In our survey of bakers, 82 percent thought that the use of freezing would become more important. Their reasons were:

	Percent
Convenience	39
General increase in frozen foods	24
Frozen results in fresher quality	14
Lower costs	14
Other	9
Total	100

5/ Marketing Frozen Bread - A Preliminary Report, by Robert V. Enochian, AMS 395, U. S. Dept. of Agr., August 1960.

Furthermore, bakers may not be the only ones to adopt the use of freezing. Other companies could, for example, set up a mix station and start penetrating a frozen market.

In summary, frozen bakery products are not the magic "open sesame" key to all the cost, price, and other problems that are now barriers to maintaining or increasing per capita consumption of wheat products. For example, more freezer space would be needed both in stores and in homes. But only a confirmed pessimist would not predict a continued growth in the various uses of freezing of bakery products. The more optimistic outlook is for this technology to trigger other developments that will stem the downward trend and possibly increase utilization of wheat in food uses.

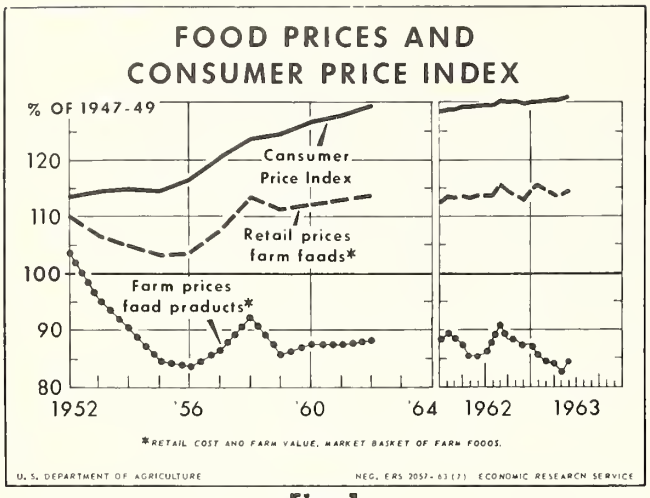

Fig. 1

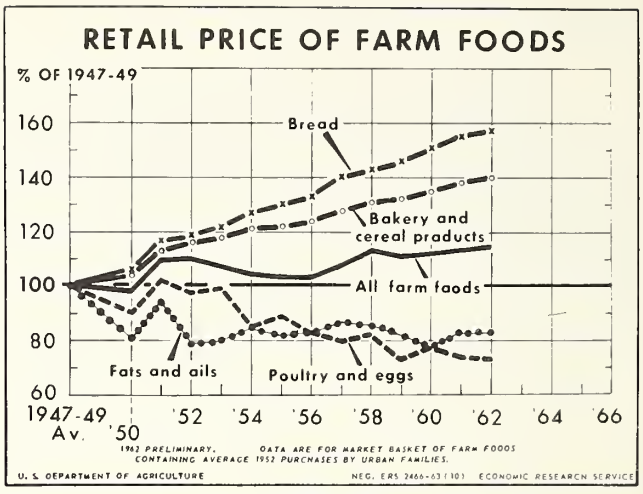

Fig. 2

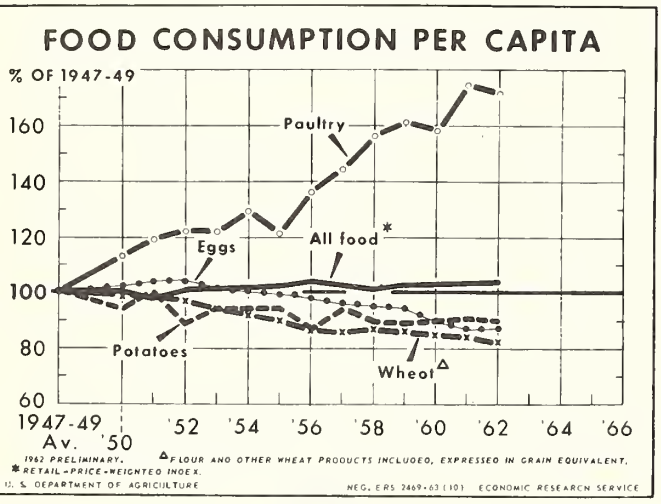

Fig. 3

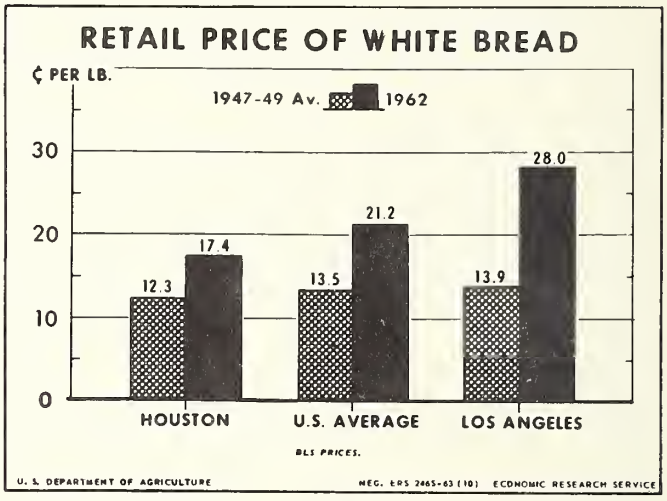

Fig. 4

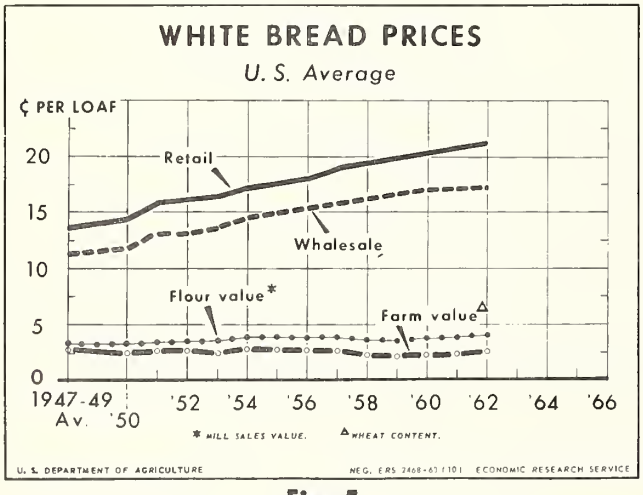

Fig. 5

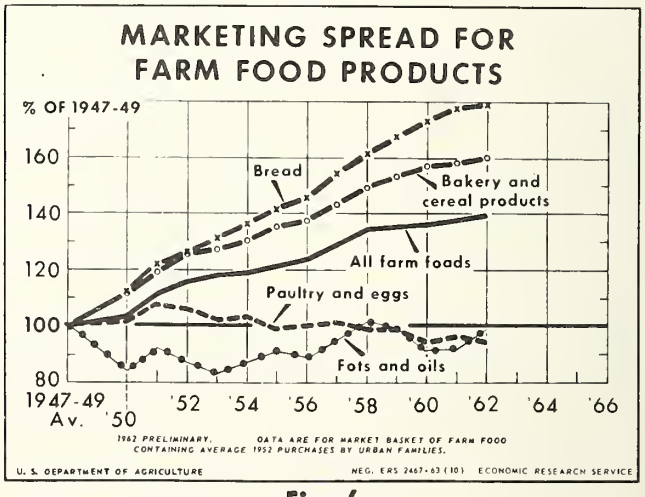

Fig. 6

ALTERNATIVE USES OF FREEZING IN THE PRODUCTION AND MARKETING OF BAKERY PRODUCTS

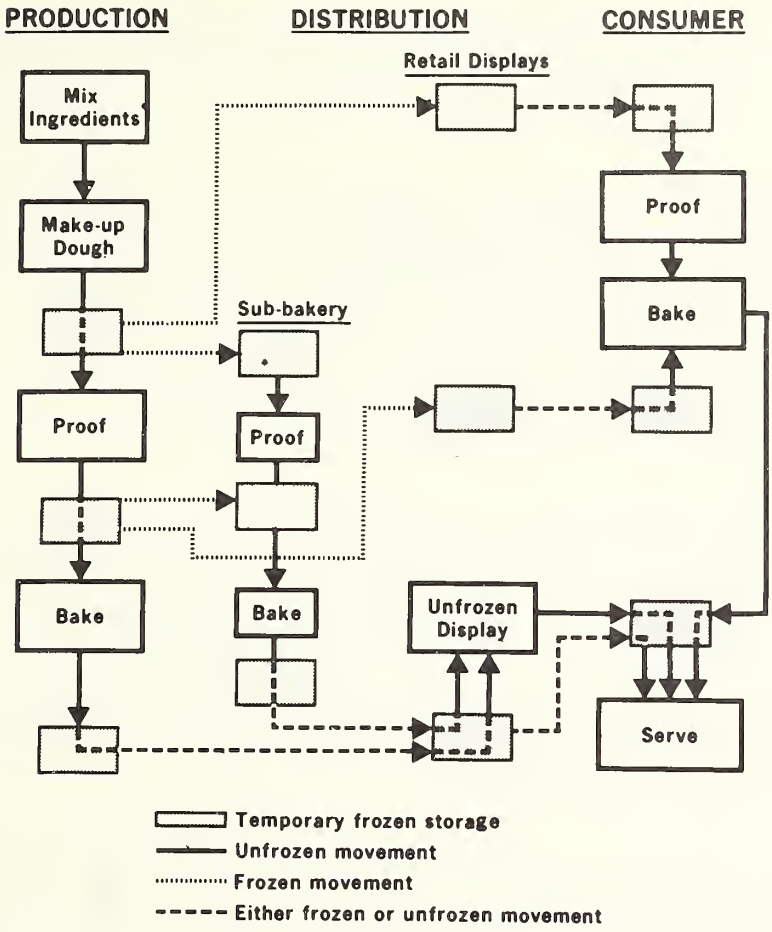

Fig. 7

Percent of Bakeries, by Type, That Freeze Bakery Products, United States, 1961.

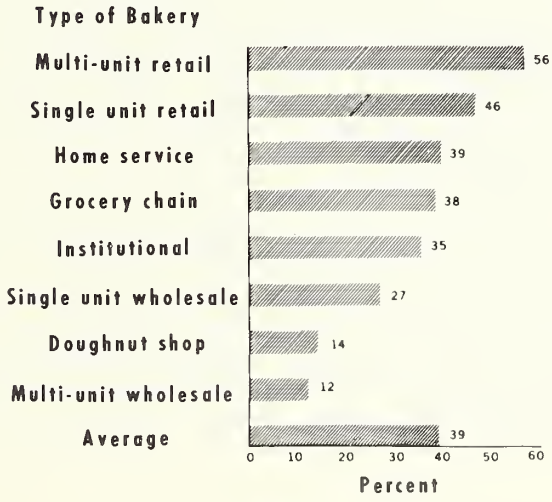

Fig. 8

EFFECT OF PROCESSING ON VITAMINS AND MINERALS OF BULGUR

J. W. Pence
Chief, Cereals Laboratory, Western Utilization Research
and Development Division, USDA, Albany, California

At the first of these National Utilization Conferences held last year in Lincoln, Mr. Rasmussen related in some detail the history, the nature, and the growing awareness of bulgur as a valuable food material that is making new markets for U.S. wheats. Yesterday, Mr. Locke provided us with stimulating new information on the present status of this new industry and the bright prospects for commercial market developments overseas. I think we can all agree that the picture is promising, but a great deal remains to be done. The material I will present today will account for a portion of the additional information about bulgur that is needed and will be useful in building markets and increasing consumption throughout the world.

Before I get into the main part of my talk, I think it would be appropriate to discuss first a particular point of some pertinence. You all have heard much said about the nutritional virtues of bulgur and wheat in general. These are important virtues, without question, but perhaps unfortunately the nutritive properties of bulgur will not necessarily induce the millions of potential users at home and overseas to buy bulgur or even to eat it if given to them. The cardinal virtues for this goal are first, palatability and then price. Other factors are also important, and a big one in some instances may be the social status of the product.

This is to say, in effect, that nutrition normally has no profound effect on sales of a food commodity, as can be attested by many examples. On the other hand, nutritional properties are far from unimportant. In the case of bulgur, they are very important. Because it is a new product in so many places and because it is being introduced so widely through government associated agencies, it is receiving a very careful scrutiny by agencies in our own government, in foreign governments, and in world governments. Such scrutiny includes a quite proper concern with the nutritional properties of the material. Those of us concerned with bulgur and its promotion, therefore, must be prepared to provide the detailed and comprehensive information that may be sought about bulgur from any quarter. Finally, proponents of bulgur can be more persuasive and effective if they are armed with full information about its attributes and any limitations it may have--above all an informed conviction that it is a good product.

From various sources most of you have learned of the somewhat primitive practices that were used to produce bulgur in the past. You also have learned the nature of our modern large-scale and continuous methods for its production. Whenever such profound innovations in food processing occur, there is also concern with possible alterations in product properties. That no significant change in appearance and eating qualities resulted from the new processing procedures was soon apparent, but only sparse information has been available

about nutritive properties, although the available information was generally pleasing. Thus our experimental objective was to enlarge the amount of nutritional information about bulgur and, especially, to determine the influence of the modern processing methods. In addition to further study of the vitamin and mineral factors about which some information already existed, we obtained information about some of the newer B-vitamins and about the protein values of bulgur. Dr. Kohler will discuss the protein quality aspect for you, in his talk.

Cereal food products have long been recognized by nutritional authorities as major dietary sources of several of the B-vitamins of which vitamin B_1 and nicotinic acid are perhaps the most widely known. Of the common cereal grains, wheat has been especially important in this regard because it comprises such a large part of temperate zone diets. Vitamin B_1 is also an important substance to study because it is so susceptible to destruction by heat and other harmful influences. This also makes it a convenient reference compound to indicate changes induced by processing.

For our experimental work, we obtained fairly large samples of both red and white wheats of the types currently used for bulgur manufacture. From each of these wheats we proceeded to make bulgurs by pressure-cooking methods and by atmospheric-pressure-cooking methods in order to determine whether the differing heat treatments caused any significant differences in vitamin contents of the bulgurs. Both types of cooking are currently being used on a large scale to produce the bulgur that is being sent overseas in such large quantities. All the bulgurs were treated in a uniform manner after cooking. Drying of the cooked wheat, debranning, cracking, and sieving were all conducted with the same equipment and in a manner reasonably representative of the same steps as are used commercially.

These later processing steps are the source of some mechanical losses of vitamins and minerals, because certain of the factors are concentrated in the bran or in the germ of raw wheat. Thus, removal of some of the bran and loss of fine material during sieving will carry away some of the nutrients. However, these losses have been found to be relatively minor because of the tendency for redistribution of nutrients in the raw wheat kernels when they are parboiled. As the raw wheat kernels are soaked in hot water, the soluble vitamins and minerals in the bran can be carried, in part, into the center portion of the kernel where they can become deposited when the cooked kernels are dried. This transport and relocation of soluble nutrients is a primary reason why parboiled wheat and rice are superior food products in comparison to ordinary white flour and polished rice. This is one of the reasons why bulgur can resemble whole wheat so closely in food values. Another important reason is that the debranning procedures generally remove only the coarse outer bran, low in food value. The more nutritious bran layers are retained in the final product.

After production of the various experimental bulgurs, the wheats and the bulgurs were analyzed for protein, ash, and fiber; for three minerals--

iron, calcium, and phosphorus; and for six of the main B-vitamins--B_1, B_2, nicotinic acid, folic acid, pantothenic acid, and vitamin B_6. Table 1 shows some of the results obtained.

Table 1.--Nutrient losses in processing wheat to bulgur

Nutrient	Number of comparisons	Percentage lost
Protein	3	0
Ash	8	9
Iron	7	9
Calcium	7	3
Phosphorus	7	8

First however, let me say that there were no significant differences in losses of nutrients between atmospheric and pressure cooking methods nor between red and white wheats. The values for each category varied somewhat, but there were no trends discernible and the values for all experiments fall in fairly narrow ranges for the most part. Consequently, results from all of the comparison experiments were combined for the table. The number of comparison experiments conducted is listed on the table to illustrate that enough values were obtained to lend validity to the average values shown for losses of nutrients due to processing.

The first point worth noting in the last column of figures is the apparent zero loss of protein. One might at first expect significant losses because bran generally is higher in protein than the starchy portion of the kernel in the center. However, as mentioned a moment ago, only the outer bran tissues are removed, and those are the lowest in protein and vitamins and the highest in fiber of the principal bran tissues. The high-protein testa and aleurone tissues are largely retained in the final bulgur product. This is not completely true for total ash content, because ash constituents are distributed somewhat differently from the protein.

The small average losses in iron and calcium need some explanatory comment. The ranges of values, averaged here, were the broadest of all those for the factors studied. There were some individual losses up to 30 percent and some apparent gains up to 22 percent. Iron and calcium values, particularly, can jump around quite a little because of the possibility of the pickup of soluble iron compounds from metal cooking equipment and of calcium from processing waters if they are high enough in mineral constituents. On the average, however, the bulgurs have virtually the same values for these factors as their parent wheats.

The next table shows the values obtained for the major B-vitamins. Here

Table 2.--Nutrient losses in processing wheat to bulgur

Nutrient	Number of comparisons	Percentage lost
Vitamin B_1	8	15
Vitamin B_2	5	12
Nicotinic acid	5	7
Folic acid	5	25
Pantothenic acid	5	24
Vitamin B_6	5	2

again, enough comparative experiments were made to make the average meaningful. The relatively small loss shown for vitamin B_1 surprised us because values from the literature were between 25 and 30 percent. The low loss value shown here probably reflects the care taken in these experiments to avoid leaching losses of soluble factors and to avoid overcooking of the wheat during the parboiling step. The range of values we obtained for the eight comparisons were from 6 to 22 percent.

The small losses for vitamin B_2 and nicotinic acid were expected because these factors are relatively stable to heat, and previous investigators have found quite good retention of these vitamins during bulgur making--provided, that is, that sun drying of the cooked wheat was not employed. Vitamin B_2 is rapidly destroyed by exposure to sunlight. Other workers have reported losses of up to 70 percent for riboflavin in sun-dried bulgur. Thus, we have a clear advantage for use of modern processing methods over traditional methods.

The losses of folic acid and pantothenic acid shown here put them in a lower stability class than vitamin B_1 but whether this will remain true for commercial bulgurs must await results of additional analytical work now in progress. So far as we know, these are the only available figures for these vitamins in this particular connection. They confirm pretty well what might be expected from experience with these factors in other foods. Still, it is important to have actual data from which one can speak with confidence, rather than trying to extrapolate from other experience as this is often very misleading. The very high retention for vitamin B_6 was a little surprising and quite gratifying because it is an important B-vitamin and is not always as stable as found here with bulgur.

To sum up the data given on these two tables, we can state that these experiments show retention of from 75 to 98 percent on the average, of a number of the more important food factors in bulgur when made from whole wheat by

facsimiles of modern processing methods. This makes a good selling point to those who are concerned about the nutritional virtues of bulgur.

A question that still might be asked about the results that were obtained is "how typical or how representative are the bulgurs and wheats used in the experiments." The next table will help to answer such a question.

Table 3.--B-Vitamin and mineral contents of bulgurs

Nutrient	Laboratory bulgurs	Commercial bulgurs
Phosphorus, g/100 g dry	0.41	0.44
Calcium, mg/100 g dry	30	39
Iron, "	4.3	4.9
Vitamin B_1, "	0.32	0.28
Vitamin B_2, "	0.13	0.07
Nicotinic acid, "	4.76	
Folic acid, "	0.046	
Pantothenic acid, "	0.76	
Vitamin B_6, "	0.19	

Insofar as comparisons are possible from available information, the average values for the laboratory bulgurs are quite satisfactorily comparable to the average values obtained for single samples of bulgur obtained from eight of the current manufacturers. I should again mention that additional values for commercial bulgurs are being obtained through the assistance of Bulgur Associates, Inc. and that values for all six of the B-vitamins so far studied will be obtained to fill in the gaps shown on this table for commercial bulgur. These samples will be analyzed in more than one laboratory so that additional sources of possible variation will tend to be averaged out in the final results.

The next table provides another comparison that is of interest in that

Table 4.--B-Vitamin and mineral contents of wheat

Nutrient	Wheat, all types	Wheats for laboratory bulgurs
Phosphorus, g/100 g dry	0.41	0.40
Calcium, mg/100 g dry	60	30
Iron, "	6.0	5.2

--Continued

Table 4.--Continued

Nutrient	Wheat, all types	Wheats for laboratory bulgurs
Vitamin B_1, mg/100 g dry	0.55	0.41
Vitamin B_2, "	0.13	0.14
Nicotinic acid, "	6.36	5.20
Folic acid, "	0.048	0.061
Pantothenic acid, "	1.37	1.04
Vitamin B_6, "	0.53	0.19

it compares the wheats used for our laboratory bulgurs and average values for wheat of all classes. The laboratory wheats included both white and red varieties.

Looking quickly down the two columns of figures, we see that for the most part, there is fairly good general agreement. The values for calcium, vitamin B-1, and vitamin B-6, and one or two others, however, are definitely higher for the wheat of all types than for our laboratory wheats. Two things should be mentioned in this regard. First, this suggests that our wheats were lower than average in some of these values and therefore the values for the bulgur might have been higher if we had started with other wheat samples.

This brings up an important point. What is an average bulgur? For that matter, what is an average wheat? You all are well acquainted with how widely the protein content of wheat can vary. Values for vitamin B-1 and some of the other factors can vary almost as widely. Thus, as we build up analytical information about bulgur, we have always to keep in mind that any particular sample of bulgur may have more of a particular factor than an average value of many samples, or it may have less. It is dangerous to generalize too much. At the same time we often are obliged to speak in general terms, but we must avoid becoming rigid in our thinking.

Now, when we think back over this nutritional information, we can understand that bulgur is a very good food--nearly as good as whole wheat. Neither is exactly perfect, of course, but then few foods even approach perfection. Some foods are better than others, but by and large, humans and animals eat combinations of foods to get the balance of nutrients they need. Some foods are eaten in larger quantities than others, and here is where one of the strong features of cereal grains comes in. Wheat and rice together provide more than half of the food calories for the entire world. They are basic foods in the full sense of the word. Of the two, wheat has some primary and outstanding advantages and these same advantages are largely retained in bulgur--notably a higher protein content and a higher B-vitamin content, both in short supply in many world areas. In fact, bulgur has some advantages over wheat itself. Two are noteworthy.

First, under adverse storage conditions, bulgur has been found to be more stable. It is far less susceptible to attack by insects and micro-organisms. Secondly, bulgur is so simple to prepare for eating. It does not have to be ground or milled nor does it have to be fermented or baked or processed in any further way. Although bulgur at present may not compete too well directly with other universally liked wheat foods such as breads, noodles, spaghetti, and so forth, the story may well be different when bulgur becomes more familiar to consumers. Certainly where facilities for producing these other items are not available or where they cost too much to produce or cook, bulgur clearly is superior.

What does all this mean? It means that bulgur is a very valuable food and might be called a true primary food--remarkably well suited for providing the bulk of calories, protein, and many vitamins at low cost for large population segments around the world whose diets need bolstering. It requires very little by way of supplementation with other food materials of a concentrate nature. For example, the high protein products from oilseed meals, milk, and other sources can be used in minimal amounts with bulgur so that their combined contribution can be spread among a greater number of people at lower cost in money and in available supplies of scarce high-protein material. In fact, bulgur is currently being mixed with nonfat milk solids and butter oil to feed hungry school children in Brazil and Chile in pilot programs that are to be expanded to a large scale within the coming year. In the talk by Mr. Olson that is to be given tomorrow, you will hear about other combinations of bulgur that are being developed for special markets.

In brief review, we have seen that the large-scale modern processing of bulgur, which has developed so recently in this country, can provide a product that retains a very large part of the food values present in whole wheat. Because wheat is a basic food material and because bulgur is the time-tested best way to provide it for human use under conditions no longer encountered in the highly developed countries, it is the ideal base material for alleviating the food problems that are encountered in so many world areas. Because of its own nutritional advantages and low cost, it is most efficient as a vehicle for distribution of high-cost protein and vitamin food concentrates to those who need them.

EFFECT OF PROCESSING ON BIOLOGICAL VALUE OF WHEAT PROTEINS

George O. Kohler
Chief, Field Crops Laboratory, Western Utilization Research and Development Division, USDA, Albany, California

In an earlier presentation, Dr. Pence has described for you the results of recent research on the effect of bulgur processing on the vitamin and mineral content of wheat. My objective is to round out the picture from a nutritional standpoint by telling you about recent results obtained on protein quality as affected by processing wheat into bulgur and of puffing bulgur to form the expanded product used in shelter rations.

By way of introduction, I would like to say a few words about the importance of protein and protein quality especially for peoples in the so-called underdeveloped countries of the world. Figure 1 is taken from the Economic Research Service (ERS) publication, "The World Food Budget." In the dotted areas the peoples are deficient in calories and in the so-called "other proteins." "Other proteins" means that group of proteins other than animal protein and the pulse proteins, the pulses being, of course, legume seeds such as peas and beans. The division is made, in the ERS bulletin, on the basis that the "other proteins" are largely cereal proteins and are relatively deficient in certain amino acids, especially lysine, as contrasted with the pulse and animal proteins. You will notice that most of the countries which are receiving relatively large shipments of bulgur wheat are countries which are deficient in "other proteins" and in calories. That is the reason that these countries are natural markets for wheat. The ERS, in this map, represents the degree of the deficiencies of calories and "other protein" in terms of tons of wheat. Each little dot represents 20,000 metric tons of wheat needed to balance the nutritional budget in the particular country in question. The total wheat needed amounts to 29,000,000 tons. For the most part, the same countries which are deficient in "other proteins" are in need of pulse and animal proteins. Realizing the need for protein in these areas, it behooves us to make available as rich a product in protein as is possible from the surplus supplies available, and it also behooves us to ensure that protein quality from a nutritional standpoint has not been impaired by any processing which has gone into the production of bulgur.

In my talk I should like to first define what is meant by "protein quality." Next, I should like to describe for you some results of "protein quality" studies of Dr. K. J. Carpenter and his colleagues of Cambridge University, England. Dr. Carpenter has been working on the Public Law 480 grant sponsored by the Western Regional Research Laboratory. We hoped that he would be here to tell you personally of his results but, unfortunately, he could not leave England at this time, so he sent me a summary of some of his data to present to you. Then, I should like to describe for you some of the results which we have obtained at the Western Regional Research Laboratory on the problem of lysine availability in bulgur from different types of wheat and in puffed bulgur as compared with the wheats from which they were made. Finally, I will try to pull together the results from other organizations to bring you up-to-date on the current overall situation.

Let me turn then to a description of what is meant by "protein quality." Animals, including man, require certain preformed organic nutrients in their diets. Included amongst these nutritional essentials are the vitamins, available energy sources, and certain amino acids called "the essential amino acids." These amino acids occur in foods largely as the building blocks of giant protein molecules. All higher animals require some essential amino acids. Some animals are more exacting in their requirements than others. For example, the rat is known to require at least 10 essential amino acids. Chicks which grow at a considerably higher rate than rats, require an extra essential amino acid, glycine, for maximum growth. Human beings, who grow at a relatively slower rate than rats and chickens, are less exacting in their essential amino acid requirements. Infants require 9 and possibly 10 essential amino acids while only 8 have been shown to be required by adults.

In addition to a qualitative difference in the spectrum of amino acid essentials, there are quantitative differences. This latter fact makes it impossible to translate animal results directly into the field of human requirements. In general, human beings require lesser amounts of essential amino acids per pound of body weight than do rats or chickens. This does not mean that rats or chicks cannot be used as experimental animals. Rather it means that by using these animals and by applying proper interpretations to the results, we have in our hands very sensitive tools for the measurement of the effects of processing on amino acid availability. For example, the results of many sets of rat and chick data have adequately demonstrated that the first limiting amino acid in wheat proteins is lysine. For this reason a great deal of attention has been given to the stability of and the fate of lysine during the milling, baking, and bulgurizing processes.

This leads to the specific subject for the discussion today. Before I go into it, I should like to mention one more important consideration in interpreting results. That is, that even when a protein in itself and by itself has a relatively low nutritional quality, if it is used in combination with other proteins with the proper amino acids to balance off its deficiencies, the combination will have a greater nutritional value than the individual protein materials. Thus, by adding meat or milk to wheat proteins, nutritional value of the latter is greatly improved. Similarly, by adding synthetic lysine to wheat proteins or wheat products, the nutritional value of the protein as a whole is greatly improved, since lysine is the first limiting essential amino acid.

One might jump to the conclusion that all wheat products should be fortified with lysine. But the two points mentioned above should first be considered. First, as in the case of the Widdowson-McCance study on children, relatively small amounts of supplementary foods can balance out cereal proteins to provide an excellent nutritional quality. Second, human beings do not require as much lysine as experimental animals and, hence, one should not be panicked by dramatic lysine responses seen in these animals. It may well be that lysine supplementation will be found to be the best way to supply lysine in some of the underdeveloped countries, but before this approach should be undertaken, we consider it essential for further work on human nutrition to be carried out under the practical conditions which pertain.

Another consideration which should be brought up is that all of the essential amino acids in different proteins are not completely available biologically. Further, processing tends to tie up or make some of the amino acids unavailable which were available in the original unprocessed food. Much experimentation has been done along this line, and it is clear that the amino acid most susceptible to processing damage is lysine.

Over the years a number of biological tests have been developed for the determination of protein quality. Most of these tests tend to give a measure of the first limiting amino acid which, as I have mentioned, in the case of cereals is lysine.

Let me turn now to a description of the work which Dr. Carpenter and his associates are doing at the University of Cambridge in England. The title of the Public Law 480 project under which they are working is "Development of rapid chemical methods for assay of changes in biological value of proteins during processing of cereal food products." Written into the plan of work of this project is the application of known and possible new methods as applied specifically to preparation of bulgur from wheat. The results which I shall report to you are a condensation of a talk given by C. K. Milner, one of Dr. Carpenter's associates, at the International Congress of Nutrition at Edinburgh last August. The initial studies were carried out to test established or suggested methods for determination of total or available amino acids to wheat products. Total amino acids were determined by the use of a modified Moore-Stein chromatographic procedure which, in their hands, has given good recoveries of known additions of pure amino acids to protein. This approach has been supplemented by microbiological procedures in some cases. Studies have been made on the use of the so-called fluoro-dinitro-benzene method for available lysine developed by Carpenter for use on meat and fish products. A great deal of difficulty was encountered with wheat products because of the special problems introduced by the high starch content. Several modifications were developed which helped somewhat but the results which will be presented using this method must be considered tentative because it has proved difficult to obtain quantitative measurements of lysine added to a product. Hence, rat and chick studies were undertaken to determine the amount of available lysine and in some cases of availability of methionine in wheat and bulgur products.

In order to obtain materials for this study, hard red winter wheat was processed into bulgur by three different methods varying in degrees of severity of treatment as shown in Figure 2. You will note that bulgur 1 was made by the mildest treatment. Bulgur 2 was made by a more rigorous process. Bulgur 3 was made by the most severe treatment. These products were fed to rats according to standard procedures. Carcass analyses for nitrogen were run, growth rates were measured, and the results were calculated in terms of "protein efficiency ratio" (P.E.R.), "net protein ratio" (N.P.R.), "net protein utilization" (N.P.U.), "biological value" (B.V.) and "true nitrogen digestibility" (T.D.). These data are given in Table 1.

Table 1.--Results of rat assays of wheat and bulgur

Test material	PER	NPR	NPU	BV	TD
Wheat control	1.12	2.54	39.7	45.5	87.3
Bulgur 1	1.23	2.54	40.0	45.6	87.8
Bulgur 2	1.01	2.31	36.1	42.0	85.9
Bulgur 3	0.95	2.17	35.8	41.9	85.4

I will not burden you with a detailed description of how each of these is calculated, but the first two give measures of protein quality based on rat growth and the last three based upon nitrogen balance; that is, the relative amount of food nitrogen which is transformed into body tissue nitrogen. You will note that in most cases the indices were lower for bulgur 2 and 3 as compared with the wheat control. This means that processes 2 and 3 were harmful to protein quality and presumably to available lysine content, since lysine is the first limiting amino acid. In the case of bulgur 1, the last four of the indices mentioned show no change in protein quality. In the case of the protein efficiency ratio, there is an actual increase. Dr. Carpenter feels that protein efficiency ratio is the one index which might be affected by food intake of the rat and, therefore, if the palatability of a product were greater than that of the raw material, an increase of protein efficiency ratio might be expected. The N.P.R. and N.P.U. values are therefore considered better measures for quality changes and these indicate about 10 percent decreases in processes 2 and 3.

In chick assays designed to show the effect of process 3 on lysine availability, wheat or bulgur 3 was added to lysine deficient diets to provide 8 percent protein. Levels of lysine were added to both rations.

Figure 3 shows that feed conversion efficiency was lower in bulgur-fed animals than it was in wheat-fed animals at each level of lysine supplementation. The amount of lysine which had to be added to the bulgur to make it equivalent to the original wheat amounted to 0.05 percent of the diet. On the basis of the bulgur or wheat fed, it was calculated that about 25 percent of the total lysine originally available was made unavailable by this bulgur process (No. 3).

Table 2 shows that application of the fluoro-dinitro-benzene chemical method for available lysine indicated there was a 13.5 percent loss for bulgur as compared with the original wheat. These results are strictly tentative since good recoveries of added lysine were difficult to obtain with cereals because of their high starch content. It will also be noted that the bulgurizing process according to Carpenter's results had no effect on the total lysine obtained after acid hydrolysis.

Table 2.--Total and available lysine in wheat and bulgur 3

	Total	FDNB Available
Wheat	2.4	2.37
Bulgur	2.4	2.05

Through chick experiments he was able to determine the amount of available methionine in wheat and bulgur. The results showed that the wheat and the bulgur 3 both contained 1.6 grams of available methionine per 16 grams of nitrogen. Thus, even the most severe process for preparation of bulgur had no effect on the availability of methionine. A combined table of the Cambridge results is shown in Table 3. You will see, as I just mentioned, the results

Table 3.--Combined table of results

Material	Available methionine	Available lysine		PER	NPU
		Chick	FDNB		
Wheat	100	100	100	100	100
Bulgur 1				110	101
Bulgur 2				90	91
Bulgur 3	100	(75)	87	85	90

show a reduction of available lysine for the chick and rat and by the chemical method for bulgur 3. Further work is going on in Dr. Carpenter's laboratory on adaptation of the chemical method for lysine availability to cereal products and on availability of other essential amino acids as affected by processing.

So much for the Public Law 480 research at Cambridge. I should now like to tell you of some of our results obtained at the Western Regional Research Laboratory on the effect on protein quality of preparation of bulgur from various types of wheat. I shall also give you some results on the effects of puffing bulgur as is done in the preparation of bulgur type shelter rations.

Table 4 shows protein, lysine, and protein efficiency ratio data on wheat products used in chick assays. Three sets of data are included in the table. Two of the bulgurs shown were prepared by the Western Regional Research Laboratory (WU) process which involves steeping for approximately 1/2 hour at

Table 4.--Protein, lysine, and P.E.R. data on wheat products used in chick assays

	WU HRW	WU club	Commercial club
Partially debranned wheat			
Protein (percent)	12.0	8.9	8.6
Lysine (g/16 g N)	2.98	3.30	3.24
P.E.R.	1.02	1.13	1.09
Crude fiber	1.89	2.26	2.12
Bulgur			
Protein (percent)	12.3	9.0	9.0
Lysine (g/16 g N)	2.58	3.26	3.06
P.E.R.		1.33	1.03
Crude fiber	1.82	1.98	1.78
Puffed bulgur			
Protein (percent)	12.1	9.1	9.3
Lysine (g/16 g N)	2.39	2.98	2.48
P.E.R.		1.04	0.76
Crude fiber	1.87	1.98	1.77

135-155° F., 1/2 hour at 155-180° F., and 1/2 hour at 180° F. followed by cooking at atmospheric pressure at approximately 212° F. for a period of 15 minutes. The product was then dried at 180° F. for 2-1/4 hours. The two bulgurs made by this process were from hard red winter wheat and white club wheat, respectively. The third sample was parboiled and dried by a commercial organization by a process which involves a much longer soaking period followed by a short high pressure cooking period. The debranning of the wheat and bulgur in all cases was carried out at the Western Laboratory.

Let us look first at the lysine values of the various uncooked partially debranned wheat products. You will notice that the hard red winter wheat shows lower lysine content per 16 grams N than the club wheats. Similarly the protein efficiency ratios of the club wheats were higher than that of the hard red winter wheat. This is in accord with the results of Lawrence at Washington State University, working under the Western Regional Research Laboratory contract, that showed wheats, lower in protein, average higher in lysine content when the lysine is expressed on the basis of grams of lysine per 16 grams of nitrogen. We see further that apparently a slight loss in total lysine occurred in the bulgur process. Looking at the protein efficiency ratios (P.E.R.'s), in the case of club wheat, there was actually an increase due to the bulgur processing procedure. In the case of the commercial club wheat,

there was a slight decrease in protein efficiency ratio due to the bulgurizing process. When we look at the puffed bulgurs we see that there has been a significant reduction in total lysine content due to the puffing and that there is a corresponding decrease in P.E.R. values. Although these differences are statistically significant, it does not necessarily follow that the puffing operation has reduced the wheat to a serious degree. Indeed, the values for the puffed bulgur are still in a range of white flour and white breads. This will be mentioned again later.

Figure 4 shows the results of a typical chick assay run at the Western Regional Research Laboratory to determine the effect of bulgur manufacture and of puffing bulgur on lysine availability. The results show that the commercial bulgur process had no detrimental effect on lysine availability. Puffing the bulgur at a temperature of 500° F. for 30 seconds resulted in a shift in the curve equivalent to 0.02 percent lysine. Calculated to a wheat or bulgur basis, this amounts to about an 18 percent loss of lysine availability due to the puffing treatment. In two other tests, wheats tested in this manner (HRW and white club, WU process) showed no loss in lysine availability due to the bulgur manufacturing procedures and in these cases, no losses due to the puffing process. You will note that all wheat preparations show higher available lysine than corn.

So much for the results obtained at the Western Regional Research Laboratory. I should now like to turn to several reports in the literature concerning P.E.R. values and lysine contents of various wheat products. I refer you first to Table 5 which shows results obtained way back in 1945 by Dr. E. Hove, et al. You will notice that in his P.E.R. rat studies, the whole

Table 5.--P.E.R. values on wheat products (Hove, et al., 1945)

	Percent protein	P.E.R.
Wheat	14.4	1.4
Patent flour	13.5	0.8
First clear flour	16.2	0.8
Second clear flour	17.4	1.2
Red dog flour	17.7	2.1
Shorts	17.4	2.5
Bran	16.0	2.1
Germ	29.9	2.9
Defatted germ	34.8	2.9

wheat showed a P.E.R. value of 1.4. Patent flour prepared from this wheat showed a P.E.R. value of 0.8 as did the first clear flour. Then as some of

the bran layers began to be included in the cruder products, P.E.R. of second clear flour rose to 1.2, red dog flour to 2.1, shorts to 2.5, bran dropped off a little again--down to 2.1, and germ showed a P.E.R. value of 2.9 which is higher than that of casein which is the standard used in the P.E.R. test. Thus, it is clear that from these data that by including the inner bran layers and germ of the wheat, as done in making bulgur, we should increase the protein efficiency ratios over a product made from essentially pure endosperm, such as white flour.

In Table 6 a similar set of figures is shown for the lysine content of various milled products. These results were reported by Dr. W. Bradley at the 1962 wheat conference in Albany, California. We see that the whole wheat

Table 6.--Lysine values of wheat products (Bradley, 1962)

	g Lysine/16 g N
Wheat	2.67
Patent flour	1.97
First clear flour	1.94
Low grade flour	2.54
Red dog flour	4.13
Shorts	4.18
Bran	3.77
Germ	5.28

contained 2.67 grams of lysine per 16 grams of nitrogen; patent flour, 1.97; and first clear flour, 1.94. Then as bran particles appear in the cruder products, low-grade flour ran 2.54 percent lysine, almost up to the original wheat. Red dog flour is considerably higher, 4.13; shorts, 4.18; bran, again, is down a little bit at 3.77 just as in the case of the P.E.R. values; and wheat germ shows a lysine content of 5.23 which is very good, being relatively close to that of soybean meal, meat meal, and other products considered to be good sources of lysine. I mentioned that the P.E.R. values which I showed a moment ago were reported in 1945; the lysine values were reported in 1962, 17 years later. Figure 5 shows that an amazingly close relationship exists between the two sets of data. This is in accord with the proposition that P.E.R. values essentially measure available lysine and is also in accord with the idea that no great difference exists in the percentage availability of lysine in various mill fractions.

You will note that the P.E.R. values which were described earlier for bulgur products were all greater than the P.E.R. values of white flours. I think it is clear that if puffed bulgur products or white flour products are used in diets where no animal, leaf, or pulse protein is added, one might

expect that lysine might be limiting even in human beings where the requirement is relatively low. However, even in underdeveloped countries, some animal or pulse protein is in the diets so that little likelihood of lysine deficiency exists where the minimal protein requirements are met. Bulgur, because of its content of bran and germ proteins, gives an extra margin of safety over more highly purified wheat products and such cereals as corn which is lower in lysine content.

Table 7 shows what we are doing when we partially debran bulgur by the peeling process which follows the cooking step. In this peeling process about 3 to 4 percent of the total weight of the kernel is removed. In this table you will notice that the outer layer or epidermis makes up about 3.9 percent of the total weight of the wheat kernel. The next layers going toward the center of the kernel are the cross layers which amount to about 0.9 percent and the testa, which amounts to almost 0.6 percent. The combined weight of these outer bran layers is only a little over 5 percent. In the bulgur

Table 7.--Percentage distribution of components in different parts of the wheat kernel (Shetlar, et al., 1947)

	Weight	Protein	Cellulose	Pentosan
Epidermis	3.9	1.2	55.2	20.8
Cross layers	0.9	.6	8.7	3.8
Testa	0.6	.7	0.0	1.4
Hyaline + aleurone	9.1	20.8	26.2	33.8
Endosperm	85.4	77	12.1	44.8

debranning process we are removing largely epidermis and perhaps a little cross layer and testa, but it is very unlikely that any of the hyaline or aleurone layers are removed. You will notice, from a glance at the protein values, that if we remove the entire epidermis, we will be removing only about 1 percent of the total protein of the kernel; but in doing that we would remove 55 percent of the total cellulose of wheat and 20 percent of pentosans. Neither the cellulose nor the pentosans are appreciably digestible by man and, in getting rid of them in the bulgur process, we are substantially upgrading the product. The hyaline and aleurone layers which remain in bulgur contain about 21 percent of the total protein of the kernel. By retaining this protein in the kernel, we are retaining the value of the protein present since the proteins in these layers contain a high lysine content. In addition, bulgur contains the germ of the wheat which is also rich in protein and, even more important, is rich in protein of high biological value.

In summarizing, I should like to make the following points. First of all, it is important to appreciate the significance of the biological measurements for protein quality and to use caution in applying animal work to human nutrition. Next, we can see animals as sensitive tools for measuring changes which occur during processing as, for example, the biological value of protein. Application of chemical and biological techniques to bulgur processing has shown that the more severe processes can adversely affect protein quality but that the milder controlled processes currently used in the U.S. are not harmful to lysine availability or bioassay results related to this measurement. Puffing causes some loss in available lysine but the products are still comparable to or superior to purified endosperm products such as white flour. It is emphasized that conversion of wheat to bulgur with removal of the outer bran layers provides a most efficient means of utilizing the valuable nutrients of wheat while, at the same time, eliminating major portions of the indigestible cellulose and pentosan of whole wheat.

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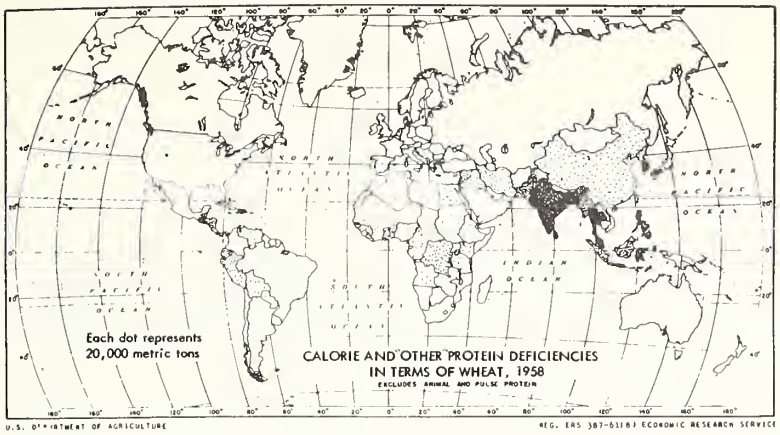

Fig. 1

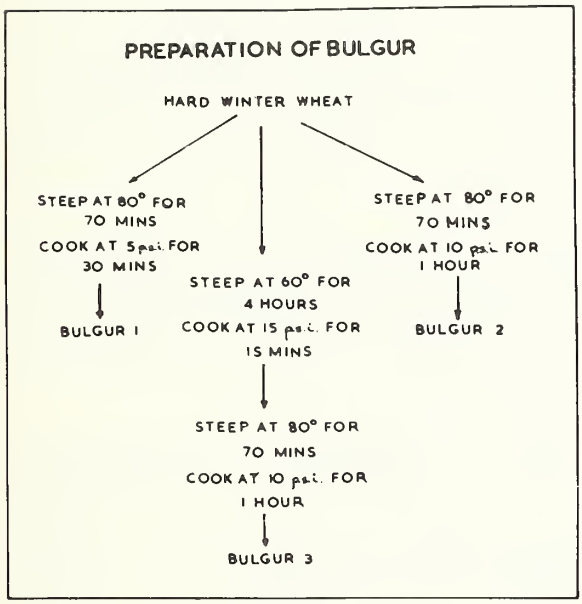

Fig. 2

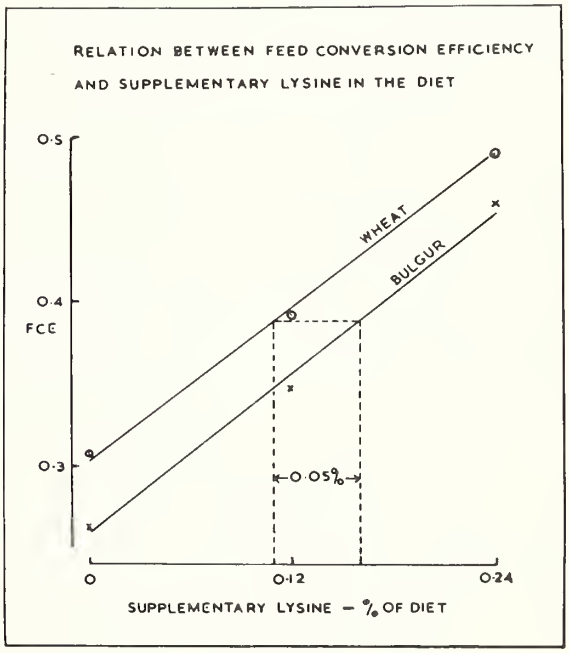

Fig. 3

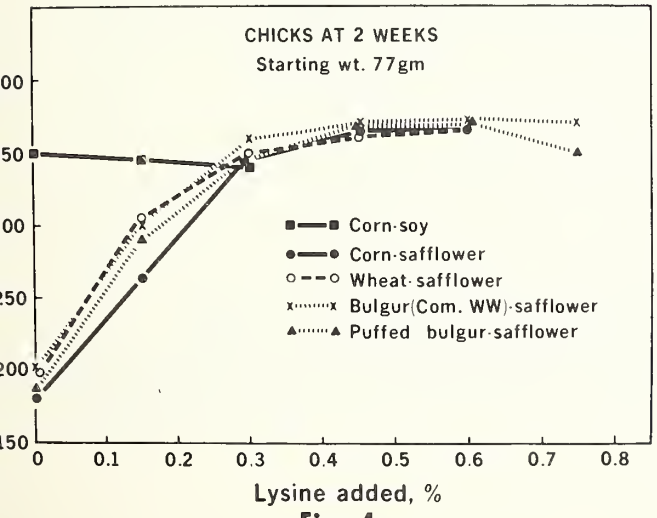

Fig. 4

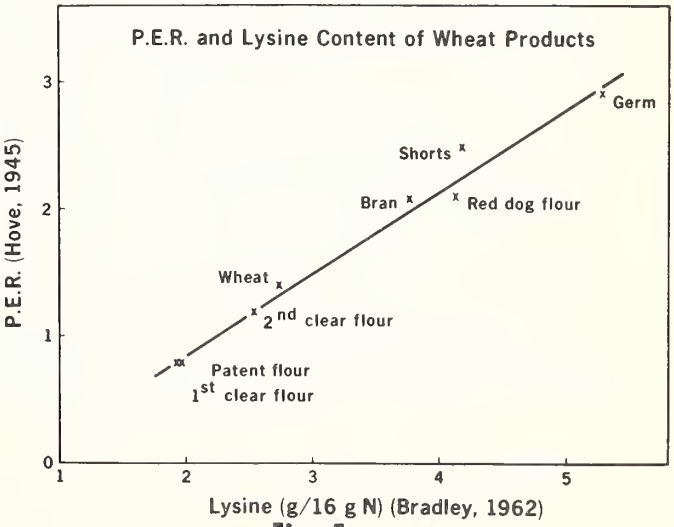

Fig. 5

DEVELOPMENT OF BASE MATERIALS FOR MILK-LIKE PRODUCTS FROM WHEAT

H. N. Draudt
Department of Biochemistry, Purdue University
Lafayette, Indiana

In many underdeveloped countries there is an insufficiency of protein foods, including low cost protein-rich beverage products suitable for young children. In some cases this need is being fulfilled by the use of "milks" prepared from various legumes.

Wheat protein could be utilized for the purpose if suitable methods were developed to produce a water-dispersible high protein concentrate from wheat or wheat flour. Lysine addition would probably be desirable and should be the only amino acid supplementation required to provide a product of high biological value from wheat.

Development of methods of conversion of some of the surplus wheat into a milk-like product for feeding children should be of benefit in solving the problem of distribution associated with the presence of food surpluses in some areas of the world and shortages in others.

The work to be discussed is being carried out as a Purdue Institute for Agricultural Utilization Research project under a contract between the Purdue Research Foundation and the U.S.D.A. Agricultural Research Service, Western Utilization Research and Development Division.

Objectives of the Present Work

It is desirable to produce both a product and a process of manufacture based on the guidance of the following specifications:

1. It should be in the form of a powder which is readily dispersible in water (hard or soft).

2. In the water-dispersed form the product should contain about 4 percent protein and 13 percent total solids.

3. It should have a bland flavor.

4. It should have a milk-like appearance and be nearly white in color.

5. It should be nutritionally sound.

The technical problems associated with the development of such a product simply involve finding a practical means of separating protein from most of the starch present and finding means of achieving dispersibility of

the largely water insoluble wheat protein by a process that produces no more than negligible damage to flavor, odor, color, and nutritional value of the protein. The costs of processing must be reasonable.

Separation of Wheat Protein from Flour by Wet Methods

The possible starting materials for producing a milk-like product from wheat include ground wheat, wheat flour, air classified high protein flour, and gluten. Hard red winter wheat, our starting material, contains about 12 percent protein and 65 to 70 percent starch. Preparation of the desired product containing a protein to solids ratio of 4 to 13 means that either starch or low protein flour fractions or both would be generated by the production of the milk-like product. One method of achieving this protein solids ratio is to utilize the high protein air classified flour fraction from hard red winter wheat and build up the protein content by the addition of commercial gluten. We expect to study this approach in some detail in the future.

Gluten makes up about 80 percent of the total flour proteins and is water insoluble. While it is ordinarily recovered from flour by virtue of its water insolubility and its property of forming a gluten ball or a coagulum, the present work was proposed to find out if it could be solubilized to separate it from the insoluble starch fraction.

Gluten proteins increase in solubility under either acidic or alkaline conditions. The use of alkaline treatments was rejected as being likely to cause damage to the protein. Acid treatment was explored as a means of solubilizing and separating wheat proteins. Hydrochloric acid was selected for this purpose because any added at the separation stage could be employed later in processing to achieve dispersibility and because residual HCl could be neutralized with sodium bicarbonate to form common salt.

In processing involving separation of proteins from flour as well as in processing to achieve dispersibility it is desirable to minimize breakdown of protein to the free amino acid stage or to small protein fragments containing only a few amino acid residues. The free amino group of the amino acids and other small fragments can be expected to lead to browning during storage of a product, even under dry conditions, producing undesirable bitterness and darkening of color. If much breakdown of protein to the amino acid stage occurs during processing, loss of nutritional value due to amino acid loss will be high during the dialysis step used later in the overall process. Thus an important aspect of the present work involves the evaluation of the effect of different processing treatments on the size distribution of the proteins and protein fragments present following specific experimental treatments.

Highly purified glutenin is an excellent model for scientific study of this question since it behaves essentially as a single protein. It is the most difficult protein in flour to disperse and it is relatively easy to obtain an estimate of the general size distribution of fragments.

Extracting flour with 0.26 percent hydrochloric acid alone extracted 51 percent of the total protein. Enzyme treatment before HCl extraction gave a yield of about 80 percent of the protein when papain was used and 85 percent when pepsin was used.

When purified glutenin was treated with pepsin under sufficiently rigorous conditions to assure that essentially all of the labile peptide bonds in the glutenin molecule had been broken, it was found that the glutenin became largely dispersible. About 50 percent of the glutenin had been converted to very large fragments (trichloroacetic acid insoluble), 45 percent appeared as intermediate size fragments (trichloroacetic acid soluble, nondializable) and only 5 percent appeared as dializable (small) fragments. When glutenin was treated with papain under conditions designed to achieve breakage or hydrolysis of essentially all of the labile peptide bonds a quite different result was obtained than with pepsin. With papain treatment, 15 percent of the glutenin remained completely indispersible, only 8 percent of the glutenin appeared in the intermediate size fraction and 77 percent was converted to fragments small enough to pass through a cellophane membrane. Thus from the standpoint of producing the desired product pepsin is more promising than papain in two respects, solubilizing the protein and providing a desirable size distribution.

While work on protein extraction has so far been carried out using wheat flour, the possibility of extracting protein directly from ground wheat will be examined. This could result in some improvement in the nutritional value of the protein since it is known that proteins from some of the low grade mill fractions contain a higher proportion of lysine than does gluten.

Dispersing Gluten

If the problem involved only the solubilizing of the gluten proteins a number of approaches suggested by the literature might be employed. Some of these possibilities include splitting of the disulfide linkages, and rigorous hydrolysis with acid or enzymes or both to break the molecule down to water soluble fragments. Some of these methods have been tried but it is clear we cannot escape the demands created by the simple fact that the material in question is to be a food product. Splitting disulfide bonds by sodium bisulfite treatment followed by oxidation produced a partially dispersible gluten but the product was inedible because of the off-flavor produced. Heating with 3 percent hydrochloric acid for example produces undesirable flavor and color. Another more gentle approach to achieve dispersibility, and one which shows considerable promise, is the partial removal of amide groups from the glutamine and asparagine of gluten by mild hydrochloric acid treatment.

It is desirable that the final product have a pH near 6.6. Gluten is least soluble and least dispersible in this range. The gluten molecules are essentially electrically neutral in this pH range because the electrical charge of positive and negative charged side chain groups cancel to give a net charge of zero. The pH at which this occurs is called the isoelectric point. Typically proteins in general are least soluble and dispersible in water at the isoelectric point. The isoelectric point occurs near the pH we want for our product. Thus, unmodified gluten exhibits the worst possible properties from the standpoint of producing the dispersible milk-like product.

If either acid or alkali is added to a gluten suspension originally at the isoelectric point (near neutrality) the gluten molecules will acquire a net electrical charge and will attract and hold water molecules and thus increase in solubility and dispersibility. It is not practical to shift the pH of our final product by making it either strongly acidic or basic. However, by suitably modifying the gluten proteins we can shift the isoelectric point (the pH for minimum net charge) so that when the product is at the desired pH of 6.6 it is several pH units removed from the isoelectric point, thus giving substantial net charge, solubility, and dispersibility.

The gluten proteins contain a very high proportion of amino acids glutamic acid and aspartic acid. These are present in the gluten largely in the form of amides. In this form ammonia is combined with the side chain acid groups of glutamic and aspartic acid as glutamine and asparagine, respectively. The amide groups are uncharged. If the amide groups are removed by splitting off ammonia, charged acidic groups remain. Converting all of the uncharged amide groups to charged acid groups will shift the pH of minimum solubility corresponding to the isoelectric point to about 4.5. Thus deamidated gluten exhibits considerable solubility and dispersibility at the pH of 6.6 chosen for the milk-like product.

Fortunately the amide groups of glutamine and asparagine are much more readily split or hydrolized by acid treatment than are the peptide bonds that hold the protein chain together. From a detailed study of the hydrochloric acid deamidation of gluten it was found that the degree of deamidation necessary to achieve adequate dispersibility with minimum hydrolysis of the protein is obtained by treatment with 0.26 percent hydrochloric acid at 203° F. for 2 hours. Only about one-fourth of the amide groups are split under these conditions.

A small amount of ammonia is liberated during deamidation and is present as ammonium chloride. This is readily removed along with the hydrochloric acid by the process of dialysis. After a short dialysis (1 hour) samples are neutralized to pH 6.6 with sodium bicarbonate and are either freeze dried or spray dried.

The ability to redisperse dried samples of the product is dependent on the method used for drying. Spray drying yields a powder which disperses to a milk-like consistency. Oven or air drying does not give a dispersible product. In the laboratory work where many small samples must be studied it is not feasible to use spray drying as a routine tool since even with a pilot plant unit a minimum of several gallons can be dried in a single test. Freeze drying appears to give results reasonably close to those obtained by spray drying and is very convenient for large numbers of small samples.

While the outlined approach produces a material having suitable dispersibility, color, consistency, and mouth feel characteristics, we do find a small but not negligible off-flavor that can be described as a "cardboard" flavor. Possible sources of this flavor include oxidized lipids or browing products. The source of this off flavor is being investigated. The outlined

process does eliminate the "raw cereal" flavor which is characteristic of a simple flour water mixture.

The approach discussed here is one which appears to be reasonable and promising based on our present knowledge, but it must necessarily be considered tentative since we are currently in the middle of our work on the problem. It is certainly conceivable that by the time we have finished our work we could recommend a considerably different approach to making a milk-like product from wheat.

DOUGH DEVELOPMENT AND ITS MEASUREMENT AS RELATED TO BREAD QUALITY

R. K. Durham
Consulting Cereal Technologist, Great Plains Wheat, Inc.
Garden City, Kansas

The character of bread, crackers or cookies made from wheat flour is definitely affected by the physical properties of the dough from which they were made. Furthermore, the physical properties of doughs made from flour and water are inherent characteristics of the wheat from which the flour was milled. These inherent characteristics may be, and sometimes are, modified during the milling process. Ingredients other than flour and water also alter natural physical dough characteristics. The fact remains, however, that unless modified during milling or by dough ingredients, dough development properties are inherent in the wheat.

The purpose of this commentary is to impress the wheat grower with the importance of dough development properties.

How much of the baking performance of flour is dependent upon inherent properties of wheat and how much is attributable to the manner in which the flour is milled? Recent inquiry among flour mill chemists reveals that from 80 percent up to 100 percent of baking performance of flour is derived from the millers grist. The remaining 0 to 20 percent is in the milling.

The terms "baking quality" or "baking value," and "baking strength" are often used interchangeably and synonymously. But, by those persons who distinguish between these two expressions, "strength" means ability of dough to retain the gas produced during fermentation. Loaf volume is then the measure of wheat or flour "strength." But when studying the several published

reports along this line one must critically examine the baking procedure to see that it is conducted so as to bring out the maximum potential loaf volume.

On the other hand, "baking quality" or "baking value" is an expression of the overall observations such as dough absorption, mixing characteristics, dough handling properties, crumb grain, and texture, as well as loaf volume. Some of these factors are not accurately measured and are subject to the personal opinion of the person who is judging the bread. Some judges of baking performance contend that dough mixing time and tolerance are equally as important as loaf volume. The advantage of loaf volume as a measure of baking potential is that it is a single measurement that can be objectively determined. Baking scores, on the other hand have not been standardized and are made up of a number of factors, some of which are highly subjective.

I therefore prefer to use the term "baking strength" when discussing the baking potentialities of wheat.

It is often stated that bread baking strength of flour is dependent upon (1) gas production and (2) gas retention properties when made into dough. In former years gas production in dough was looked upon as a wheat or flour property and was given only a little less importance than gas retaining ability. But now we know that the gas cells found in bread were originally incorporated into the dough during mixing, punching, rounding, and molding. The yeast organism does not originate gas cells but does generate carbon dioxide gas which enlarges the existing cells in dough. Nowadays gas production is no problem. Increased amounts of sugar, yeast, and yeast food; more general use of diastatic supplements in the dough formula; larger but controlled amount of susceptible starch produced during the milling process;--all provide the baker with means to assure ample gas production. It is therefore generally agreed that loaf volume which is a measure of baking strength depends upon the ability of dough to retain gas. And this is dependent upon the amount and quality of the gluten and its physical condition.

In the production of bread or crackers or cookies each step from flour to baked product essentially involves physical condition of the dough. In fact, if one looks back to the days of hand baking he realizes that feeling and observing doughs under a variety of conditions is one of the oldest quality tests for flour. Mechanical manipulations and chemical changes are taking place during dough mixing, fermentation, and makeup but the outward manifestations, that is, the effects the baker sees, feels, and hears in the dough are physical.

The first and most important physical property of flour dough that the commercial baker observes is its performance in the dough mixer. By evolutionary steps during the past 30 years, the revolutions per minute of large dough mixers has increased from 40 to 50 up to the present day high-speed mixers turning at 80 or 90 rpm. In retrospect, it is now realized that doughs were probably never mixed to optimum development in the slow-speed mixers. The result was what would now be called under-mixed doughs that produced loaves having less specific volume than would be generally acceptable today.

Using present day high-speed dough mixers it is possible to attain optimum dough development. In other words, the flour protein plus added water forms gluten which by the action of the mixer is transformed into very thin films surrounding incorporated air cells.

Optimum specific loaf volume with accompanying good grain and texture is possible only if the gluten has been brought to its optimum extensibility in the mixer. Gluten that is either under or overmixed results in inferior bread. Many practical bakers depend upon the sound that the dough makes in the mixer bowl to determine when the dough is properly mixed. Others employ recording devices. But regardless of how he judges when a dough is in its optimum physical condition he insists that the optimum mixing time of his flour be such that it fits into his shop schedule and that it is reasonably tolerant to under or over-mixing. Furthermore, the mixing time must not vary from shipment to shipment. This is becoming more and more important with the introduction of continuous dough mixing systems in bread bakeries.

I repeat for emphasis. It is a proven fact that dough mixing time and mixing tolerance are inherent properties of the wheat from which the flour was milled. These properties may be somewhat modified by certain permissible dough ingredients such as salt, sugar, oxidizing agents or fungal enzymes. Likewise dough temperature. But the baker seriously objects to such dough formula changes.

Some factors that influence inherent mixing time and mixing tolerance in wheat are (1) wheat variety, (2) amount and quality of protein, (3) area where grown, (4) class of wheat, for example, spring or winter, hard or soft, (5) weather conditions such as temperature and humidity during ripening period. It is therefore apparent that the wheat producer plays an important role in dough development as it relates to bread quality. Upon the wheat flour miller falls the responsibility to select and blend wheat that will yield flour having mixing characteristics to meet the bakers specifications. But the miller is limited to the wheat which is available.

Premium price is usally paid for wheat having long mixing time with its accompanying strong bread baking potentialities. This is not necessarily because commercial bakers prefer very strong flour. In fact, they prefer medium strength--medium mixing time flour. There is normally a surplus of low strength--short mixing time wheat. Stronger winter wheat for blending with this weak wheat to bring it up to a medium level has been in short supply for several past years.

Two well-known laboratory recording dough mixers--the Farinograph and the Mixograph--together with the recently introduced Rheograph make it possible to determine the relative mixing time and mixing tolerance of flour.

Figure 1 illustrates Farinograph dough development curves for three types of flours. In each case the dough absorption is adjusted so as to center the band at its peak on the 500 line. It will be noted that three curve dimensions for each flour are shown, namely, dough development time;

stability; and mechanical tolerance index (M.T.I.). Farinograms are helpful as a guide to comparative mixing strength and tolerance. This was more true in the period before high speed mixers came into general use. Although saleable bread can be made from flour represented by the lower or weakest curve, the wheat that produced the upper or strongest curve almost always commands a premium price in the market. Farinograms made by spring wheat flour generally show greater strength than hard winter wheat of approximately equal protein content when grown in the southwest Great Plains area. Hard winter wheat harvested in the northwest spring wheat area, however, yields Farinograph curves equally as strong as hard spring wheat.

Figure 2 illustrates four types of Mixograph curves. Differences between two wheat varieties as well as differences due to environment are also shown. The upper left hand curve indicates greatest mixing and baking strength. The lower right hand curve denotes a very weak flour--undesirable for commercial bread baking. The Mixograph will rank a series of flours in nearly the same order as the Farinograph regarding strength.

Interstate Bakeries Corporation has become convinced by experience that conventional laboratory tests do not provide information that is sufficiently meaningful to predict a flour's performance in a commercial bakery. By evolutionary steps during a period of several years, this baking firm has developed a recording dough mixer named Rheograph.

Figure 3 shows Rheograph curves made from two typical flours that differ widely in mixing and baking performance. The three most important items to be observed are (1) fatigue time, (2) percent relative absorption, and (3) width or amplitude of the band and its slope after passing the peak. Fatigue time is a unique feature of the Rheograph curve which differentiates it from the Farinograph or Mixograph. The lower curve shown in Figure 3 clearly illustrates what is meant by fatigue time. The mixer is run at slow speed for 2 minutes then switched to higher speed. The curve rises to a peak then declines until a point is reached when the dough loses its resistance to mixing. The curve from this point on, if mixing is continued, becomes a narrow band which is probably a recording of the power required to run the mixer without dough. See left hand side of lower curve. The point at which dough ceases to offer resistance is its fatigue point and is expressed in minutes from time mixer is started. It is quite sharp for most flours and is reproducible.

The Farinograph indicates relative flour absorption by finding that amount of water required to center the curve band at its peak on the 500 line of the chart. The Rheograph, on the other hand, determines optimum relative absorption by a totally different method. If a series of Rheograph curves are made on a given flour with water absorption as the only variable, it will be found that the fatigue time is shortest at one absorption level. It will be longer at both higher and lower absorptions. That percent absorption which results in shortest fatigue time of the series has been found to indicate the optimum relative bakeshop absorption for the flour being tested.

The designers of the Rheograph are bakers. They claim that this physical dough testing device is capable of indicating mixing requirements and tolerance, correct absorption level, response to fermentation, response to several dough ingredients, and finally baking quality of flour. They further claim that the physical characteristics revealed by the Rheograph has made it possible to eliminate routine test bakes as a means of evaluating flour.

If we accept the belief that 80 to 100 percent of the baking performance of flour is dependent upon the wheat from which it was milled then it becomes obvious that considerable emphasis must be given to the evaluation of baking strength inherent in the wheat. This points to the need for a method to appraise the strength and quality of wheat without going through the lengthy steps of experimental milling and subsequent detailed testing of the resulting flour. As a contribution to answering this need, researchers at Interstate Bakeries, Inc. have developed a procedure to make Rheograph curves on finely ground whole wheat meal.

Figure 4 shows typical Rheograph curves on whole wheat meal. The procedure is described in July 1963, Bulletin of the Association of Operative Millers. The curve starts at right hand side of chart. The upper curve represents a mill mix made up of 100 percent hard spring wheat. The lower curve was made on a mill mix composed of medium strength southwestern hard winter wheat. Fatigue time, relative absorption and shape and width of curve band are the meaningful items to look for when appraising baking strength and quality of wheat.

Wheat mill grists together with flour milled from these grists have been obtained from five hard winter wheat mills in the Southwest. Rheograph curves were made on flour and on wheat meal. Fatigue times for both wheat meal and flour are shown in Figure 5. The relationship between flour fatigue time and that for wheat from which it was milled is quite satisfactory. Flour fatigue time is somewhat affected by oxidation and malt treatment at the mill. Had fatigue times been determined on the untreated flour, the two lines on this graph would probably have been more nearly parallel.

Protein content of the mill grist is shown in percent along the bottom of graph for information only.

Efforts by profound researchers are being continued to learn more about the effect on physical dough properties of the chemical constituents of flour and the chemical changes that take place during fermentation and mixing. Also to study the effect of dough ingredients.

Such investigations are extremely important. But one must not lose sight of the fact that these chemical effects manifest themselves in the physical properties of dough. By judicious use of this knowledge it is possible to modify to some extent the rheological character of dough.

Conclusion

There is abundant evidence in the literature to prove that physical properties of wheat flour doughs are extremely useful in the evaluation of baking performance of flour or the wheat from which it was milled.

Inherently long dough mixing time generally indicates greater bread baking strength. Premium price is usually paid for wheat having long mixing time with its accompanying strong bread baking potentialities.

Each year cereal chemists meet in Kansas City and Minneapolis to discuss the desirable and undesirable characteristics of newly developed varieties of hard wheat. Whether or not a new variety is released for widespread production depends upon the results of collaborative testing in mill, bakery and experiment station laboratories. Almost without exception, if a new variety is approved it must possess strong physical dough properties, that is, long mixing time and tolerance. Strong bread baking potentialities are then usually assured.

Now the problem is this. A practical, acceptable way must be found to make it profitable for wheat producers to grow the potentially strong varieties.

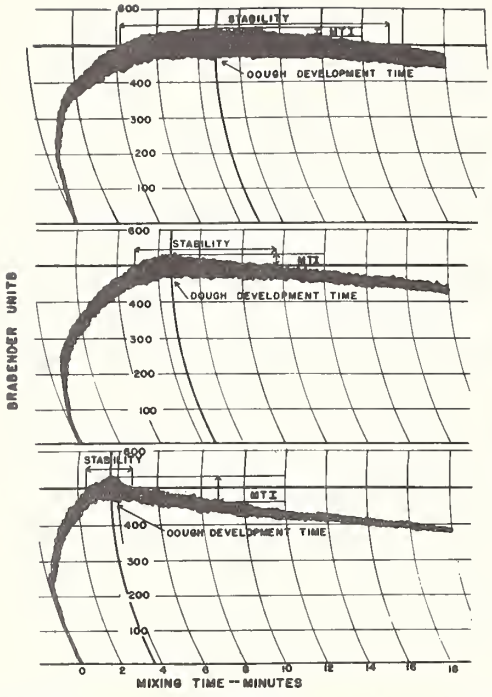

Fig.1 Typical farinograms of flour samples with a long, medium, and short dough-development time, showing values for stability and mixing tolerance index (MTI).
From USDA Production Report 9.

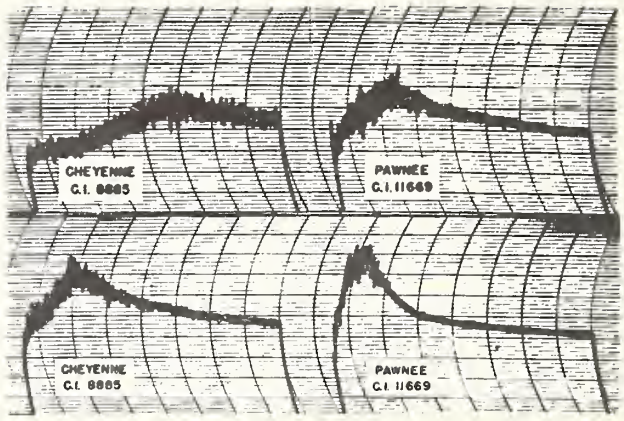

Fig. 2 Mixograms of flour samples showing the effect of environment on Cheyenne and Pawnee wheat grown at Lincoln, Nebr., (top) and at Clovis, N. Mex., (bottom).
(Courtesy of K. F. Finney, Fed. Hd. Winter Wheat Qual. Lab.)
From USDA Production Report 9.

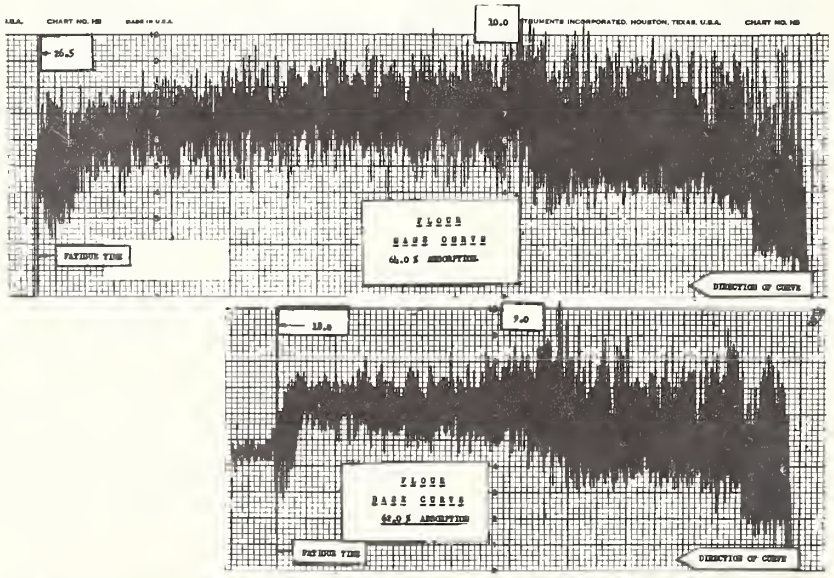

Fig. 3 Rheograph curves made from two typical flours that differ widely in mixing and baking performance.

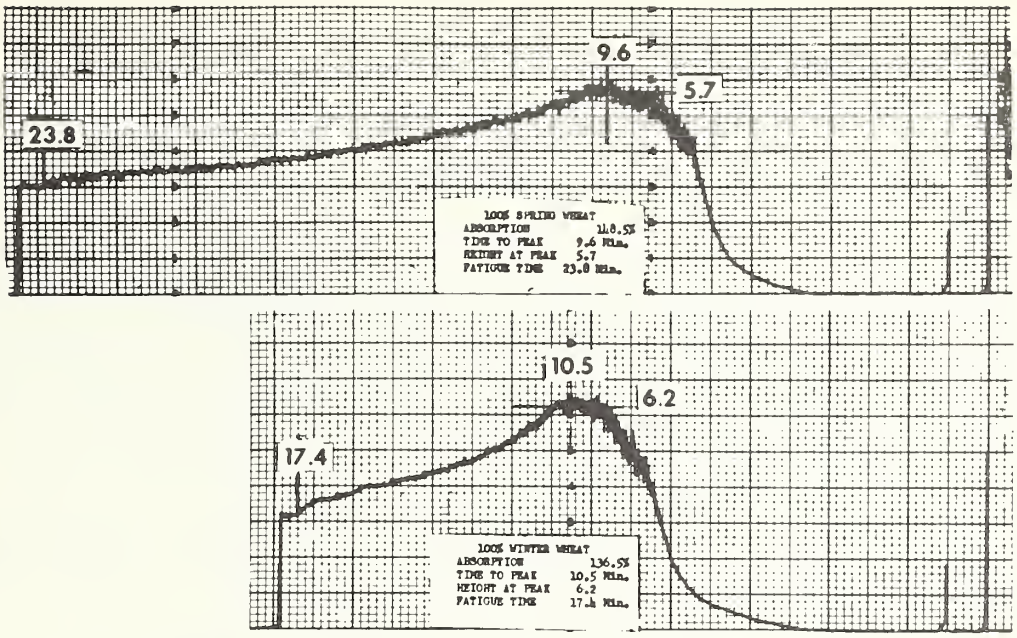

Fig. 4 Wheat meal Rheograph curves on two mill mixes.

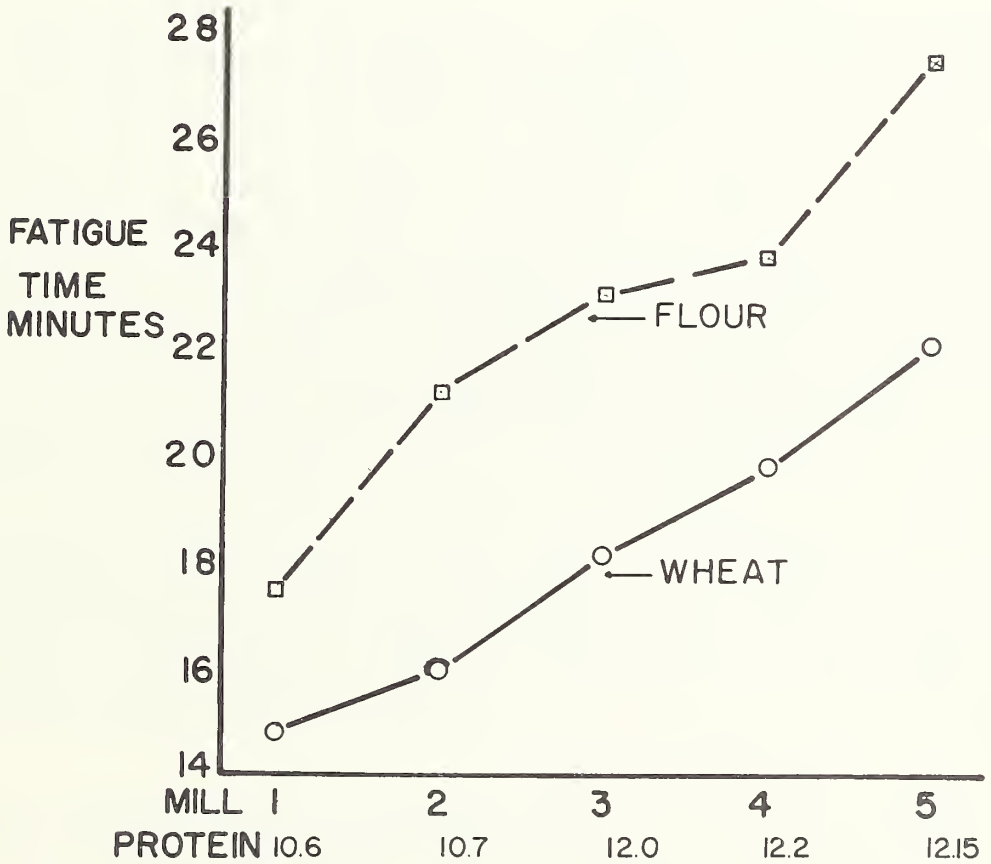

Fig. 5 Relationship between Rheograph curve fatigue times on wheat meal ground from mill mixes from five different mills together with fatigue times on flours milled from these mixes.

MICROBIOLOGICAL RESEARCH ON WHEAT AND FLOUR

C. W. Hesseltine[1] and R. R. Graves
ARS Culture Collection Investigations, Fermentation Laboratory,
Northern Utilization Research and Development Division, Peoria, Illinois

In the beginning, we would like to dispel a concept held by many uninformed persons that all microorganisms are bad. Nothing could be further from the truth. We need only turn to the use of wheat in flour for an excellent example of this. In the making of bread, yeast is purposively added to the flour to make it raise. In the past, the so-called sour-dough bread, was made by simply depending upon the natural flora of flour growing after the addition of moisture to raise the bread. Cheese is prepared by the use of helpful bacteria which run into the thousands per gram of product. Less well-known is the use in the Orient of certain beneficial molds and bacteria in the preparation from cereals and legumes of such foods as soya sauce, miso, and tempeh. Silage is prepared on many farms--a product dependent upon the action of the natural bacterial flora on the surface of the plants. We recently wrote an account of microorganisms in which we surveyed the literature for their numbers. It indicated there are about 80,000 to 100,000 different kinds of fungi, and still only 2 or 3 dozen species are pathogens for man.

Wheat, as it grows and ripens in the field, is exposed to insects and microorganisms of the air. Microorganisms from the air originate from the soil and from dead plant material. In most cases, this microflora is a saprophytic one. Most of this population actually serves a useful purpose by reducing plant and animal material to humus, thus returning essential plant nutrients to the soil for use again by plants. Many of the microorganisms in the soil are blown by the wind and naturally some of these fungi and bacteria, alight on the wheat. During harvest, the wheat kernel is exposed to additional dust and therefore to additional numbers of microorganisms. This is not a unique situation for wheat, for all feeds and foods in nature are subject to this surface contamination. For instance, Frazier (1958, p. 61) in his recent textbook on Food Microbiology, points out that unwashed cabbage has a natural population of 1-2 million microorganisms per gram and that even after washing, this material still has a population of 200,000 to 500,000 per gram. With wheat, there is no increase in numbers of bacteria simply because the raw product is kept dry under normal conditions and no further multiplication occurs. In fact, all reason and evidence would indicate a decrease in the microbial population. This characteristic property of the product--its dryness--is not found in many other plant and animal sources of food. These sources have sufficient moisture to allow an increase in numbers of microorganisms. Of course, if wheat is somewhat moist during storage, a few special types of molds develop, but in this country we would judge that very seldom does the bacterial flora increase in number except when the wheat is grossly mishandled.

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[1] Presented by Dr. Hesseltine at the Second National Conference on Wheat Utilization Research, Peoria, Illinois, October 28, 1963.

Before leaving the introduction of this topic, we want to make one fact very clear--most microorganisms, including bacteria, are not pathogens to man but actually are very useful to him. Probably if it were not for microorganisms, species of mammals, including man, would never have existed.

The object of this paper is twofold. Firstly, to review the microbiology of flour--especially flour made from wheat, and secondly, to outline the methods currently being used at the Northern Regional Research Laboratory to investigate the microbiology of wheat flour and the types of microorganisms present in refrigerated products made from flour. The immediate objective is to determine the type(s) of microorganisms responsible for spoilage of refrigerated moist flour products, and to determine if such organisms are present in flour. With an understanding of this microbiology, the ultimate objective will then be to devise chemical or physical methods applicable in the industrial milling of wheat to reduce or eliminate the objectionable microorganisms causing deterioration of products made from flour, if such microorganisms actually exist in flour.

PART I.--REVIEW OF THE MICROBIOLOGY OF FLOUR

In any review of the microbiology of flour, one must take into consideration the microflora of the grain prior to milling. However, we have excluded from this review the occurrence of microorganisms, especially fungi, from stored grain. This subject has been extensively studied by investigators at Iowa State University (for corn) and at the University of Minnesota (for wheat). Several excellent reviews on microorganisms in stored grain have been published (Semeniuk, 1954, Christensen, 1956, and Christensen, 1957).

We have also excluded from this review, the extensive literature on ergot, rusts, and smuts in grain and flour. No attempt has been made to cite all the literature on ropy bread. The problem of rope in bread caused by the growth of the bacterium, Bacillus subtilis (B. mesentericus, B. panis, etc.) is described by Frazier (1958) and a more detailed account by Barton-Wright (1943). Control methods are described in "The Story of Mold and Rope," (E. I. du Pont de Nemours & Co., 1948). Likewise outside the area of this review is the subject of molds on bakery products and their control. We have also purposely excluded from consideration control methods described to reduce the numbers of microorganisms and insects from wheat.

Although most of the literature deals with wheat flour, we have also considered flour and meals prepared from other cereals such as rice and corn. In as many instances as possible, the original source data was consulted. For this review, we have searched Review of Applied Mycology, Biological Abstracts and Chemical Abstracts, as well as the references given in the papers reviewed below. Both Frazier (1958) and Tanner (1944) have chapters on the microbiology of cereals and cereal products.

It is interesting to note that Bainier (1880) reported Aspergillus candidus (he called it Sterigmatocystis alba) in flour in France and 5 years later, Laurent (1885) in Belgium, studied the rope problem and reported the

causal microorganism to be Bacillus panificans. He recognized that it could be controlled by the use of acetic acid.

Wheat Flour

Wheat Flour--United States

As early as 1909, Bell compared the microorganisms in a patent flour and a baker's flour stored under the same conditions and reported larger numbers in some cases of bacteria and fungi in baker's flour than in patent flour. Turley (1922) reported the bacterial counts on 17 flour samples and found they varied from 250,000 to 5,200,000 per gram. In an outbreak of mold in bread, Frazier (1923, 1923) found the flour being used in a particular bakery had as many as 11,000 mold spores per gram. It was noted that bread from this bakery showed mold development within 1-1/2 to 2 hours after removal from the oven. Dupray (1923) discussed the difficulties in obtaining a reliable count of microorganisms in flour. According to Gustafson and Parfitt (1933), Fred (1929) examined five samples of flour and found the numbers of bacteria per gram to range from 18,000 to 60,000.

Flour samples made from soft winter wheat from 19 mills were studied by Gustafson and Parfitt (1933). The total bacterial count of flour was lower than the total bacterial count of wheat from which the flour was made. The bacterial count for patent flours ranged from 9,000-146,000; for straight flours 30,000-180,000, and for clear flours 30,000-380,000. The bacterial count of flour tended to decrease with the length of time of storage. With the flours they examined, the total bacterial count did not appear to be a major factor in the development of rancidity.

Holtman (1935) investigated the microbial content of flour as a result of a southern milling company reporting difficulty in the keeping quality of flour and its rapid development of rancidity. Nutrient agar was used as a plating medium and the inoculated plates were incubated at 37° C. for both the mold and bacterial counts. This study showed flour from a bin of fresh flour had a bacterial count of 23,000 and a mold count of 1,800. However, flour from the same mill but stored in a warehouse for several months showed a bacterial count of 337,000 and a mold count of 30,000. Sampling at various stages in the milling operation indicated a decrease in bacteria through the various stages of milling. Obviously the difficulty was too much moisture during storage. Further study of 21 different brands of flour obtained on the open market showed the bacterial count to range from 3,100 to 7,500 colonies per gram and the mold count from 100 to 640 per gram. The bacteria most commonly found were Aerobacter aerogenes and Bacillus mesentericus. In addition, Sarcina, Achromobacter, Flavobacterium, and Cellulomonas were present.

Hoffman et al. (1937) examined hundreds of flour samples including patent, clear, rye, and whole wheat and found the rope count to run as high as 150 colonies per gram of flour although many samples were free of the rope organism. These flours were examined during 1926, 1927, and 1928. During the next 8 years following 1928 no rope spores were found in the flour samples examined.

Boruff et al. (1938) reported a method for counting bacteria in grain which may be used not only for grain but also for counting bacteria in husks of grain, flour, and related materials. Bacterial counts indicated the following average counts per gram: barley malt 3,900,000; rye malt 2,600,000; rye 770,000; and corn 240,000. The contamination of cereals (59 samples) by thermophilic microorganisms was investigated by Yesair and Cameron (1942). They found cornmeal to have more thermophilic bacteria present than wheat flour and they judged that wheat flour was suitable for canned meats and other nonacid canned products. Tanner (1944) cites the work of Yesair and Reed (1939) who found wheat flour over several years' time not to contain canned food spoilage bacteria.

According to Nagy (1948) the chief source of mold infection in bakeries was flour. In 10 flour samples which he examined, counts of 385 to 3,700 per gram were obtained.

An outline for the bacteriological examination of cereal products has been given by Goresline et al. (1945).

The most extensive studies of wheat flour has been the work at Minnesota. Christensen (1946) studied the quantitative determination of molds in flour. In sampling flour for fungi, he stated the most important variables in determining the fungi present were: the medium used to culture the fungi; the technique of making dilutions, and the method of counting the number of colonies in the agar plates. Of the five media tested for isolation purposes, the best proved to be a malt salt agar. It contains the following ingredients:

Malt extract - 20 g.
Sodium chloride - 75 g.
Agar (crude) - 20 g.
Distilled water to make 1.0 liter.

This medium gave higher counts than the other media, including potato dextrose and acidified potato dextrose agars. The highest counts were obtained when the flour sample was diluted in a liquid with quartz sand. The suspension was then plated out in the normal fashion. Colonies were allowed to develop both at the surface and below the surface of the agar. Lower counts were obtained when counts were made with the flour added dry or the liquid dilution placed upon the surface of solidified agar. It was also necessary to examine the plates, when making counts, with a binocular microscope with an approximate magnification of X 10. Typical counts of molds using the binocular microscope showed the following numbers per gram of flour:

First break - 1,800
First clear - 3,720
Fine-1-tail - 5,220
Suction - 5,860
Coarse-2-tail - 7,350

In this paper, Christensen gave a detailed description of the procedure recommended for the counting of molds in flour. He believed the molds were uniformly distributed in flour and, furthermore, he stated "Evidently the molds were distributed with surprising uniformity in the samples taken from different streams."

Cohen and Christensen (1947) reported the range in counts of molds from 200 samples of wheat flour to be from 200 to 6,000 colonies per gram. A variation of 50 percent above and below the average count from various flour streams from one mill was encountered. Some flour streams had consistently higher mold counts than others and all streams were consistently higher in mold counts than the wheat from which the flour was made. The molds most commonly encountered were Aspergillus candidus, Aspergillus glaucus group, and Penicillium sp.

Christensen (1947) reported an examination of over 100 flour samples from mills in different parts of the United States. The mold count varied from 200-5,000 colonies per gram with the higher counts in flour milled in the more humid regions. Aspergillus glaucus and A. candidus were the predominate molds although occasionally large populations of green penicillia were encountered. He concluded that molds in flour may be excluded from the bread spoilage problem.

Sick wheat was produced in the laboratory by storing sound wheat at 18 percent moisture in an investigation by Milner et al. (1947). Flour was milled from the sick wheat thus produced. The control or good wheat showed the highest concentration of fat acidity in the bran fraction. On the other hand, flour milled from the sick wheat showed the highest fat acidity in the low-grade flour. Fat acidity increased in all samples of wheat stored at 18 percent moisture whether stored under carbon dioxide, nitrogen or oxygen but only under oxygen did molds develop.

Christensen (1949) stated that among the molds commonly encountered in bread, only molds such as Aspergillus glaucus and A. candidus also occur in flour. Other typical bread molds such as Neurospora and Rhizopus are not usually found in flour.

One of the most important investigations of the numbers, kinds, and sources of fungi in flour was made by Christensen and Cohen (1950). They investigated about 500 samples of flour from 16 commercial mills and a few from bakers over a period of 4 years. Some samples were collected in small sterile paper bags inserted into the spout of different streams. The sample sizes ranged from 4 to 16 ounces. Dilution plates were incubated at 21-23° C. for 5 to 7 days before counting. The mold counts ranged from several hundred to five thousand colonies per gram of flour.

Three samples of washed wheat had a lower mold count (a few hundred molds per gram) than the count of the flour prepared from unwashed wheat (several thousand molds per gram). When residual flour was collected from the interior of the mill machinery, counts from several thousand to several

million molds per gram were obtained and these were the same species found in finished flour. This would indicate that the source of contamination of flour was growth and sporulation of the molds in the mill itself. Thus, typical data from samples of wheat in a mill were as follows:

Wheat before washing	- 2,800
Wheat after washing	- 300
Tempered wheat	- 300
Bran	- 2,600
Shorts	- 3,200
Patent	- 1,800

One could argue that the higher counts were due to the fragmentation of the mycelium of the storage molds in the wheat kernels. In one sample, the original count of the washed wheat was 100 percent Alternaria colonies and yet the mold colonies from the bran and shorts were composed of only 5 percent Alternaria colonies.

The species of molds found in flour numbered about 20 species belonging to 8 genera. However, Aspergillus glaucus and Aspergillus candidus made up 60-90 percent of the counts in the majority of the samples regardless of the location of the mill, the type of wheat milled, or the time the samples were collected. The principal molds found were those known to grow and sporulate at relative humidities below 75 and 85 percent. Mold numbers decrease gradually in stored flour. For instance, these authors found that a patent flour with an initial mold count of 3,600 had, after 4 years, a count of 1,400 with the same types of molds present as when first examined.

Sorger-Domenigg et al. (1955) showed that samples of wheat heavily infested with molds gave flour of high ash content and poor color. Bread baked from such flour had poor baking strength and loss in baking quality.

Pomeranz et al. (1956) used wheat with a mold count of 1,000 colonies per gram and stored it at 11, 18.5, and 23.5 percent moisture at temperatures of 1-2 and 20-21° C. The wheat was then milled. At 1-2° C. there was little or no change in any of the samples. The samples stored at 11 percent moisture levels at 20° C. showed little or no change except there seemed to be an improvement in the baking quality of the flour. The samples stored at 20-21° C. with moisture contents of 18.5 and 23.5 percent showed the following: (1) The mold population increased from 1,000 colonies per gram to 6,700,000 in 8 weeks at 18.5 percent and to 4,900,000 at 23.5 percent moisture levels in 4 weeks; (2) the fat content fell with an increase in fat acidity; (3) there was a decrease in test weight but an increase in flour yield upon milling. The increase was due to a greater bran fracture and in a greater production of break flour; (4) the flour made from this wheat had a poorer color; (5) the nicotinic acid and thiamine content fell while the riboflavin content increased, and (6) reducing sugars increased.

A number of experiments were performed by these workers in which individual mold cultures were grown on bran and added to the flour from which

bread was made. Aspergillus flavus and A. ochraceus were especially deleterious to the flour and this adverse effect was attributed to the proteolytic enzymes formed by these molds.

Dack (1961) studied 10 flour samples taken from plants preparing precooked frozen foods and found the numbers of bacteria to range from 575 to 18,300 per gram with a mode of 7,000. In these samples, 4 had counts of over 10,000. In 2 out of the 10 samples, staphylococci were found and 5 had coliform bacteria. However, the coliform bacteria are certainly not all of fecal origin. He points out the need for more information on the origin of coliform bacteria in flour.

The control of bacteria in the milling of wheat has recently attracted the interest of some investigators, including Doty (1961). One of the problems is the elimination of bacterial slime and odor from the washing and tempering areas of the mill. A second is the reduction of the total bacterial count of flour and the elimination of rope spores. One of the methods tested was the chlorination of the water used in washing and tempering of wheat. Doty stated that wheat with a count of 1 million bacteria per gram, just in the milling process, is reduced to a count of 25,000 to 50,000 per gram. Customers buying flour have wanted a product with no more than 15,000 microorganisms per gram for canned biscuits, no more than 10,000 in flour for frozen fruit pies, and no more than 500 in flour for TV dinners and frozen meat pies. Chlorine treatment of the tempering water, when handled properly, could bring the count down to 10,000 to 15,000 bacteria per gram. Even with treatments of chlorine at levels of 200 p.p.m., the count could not always be brought to a level of 10,000 bacteria per gram. A more effective method was a double treatment of chlorine once on the tempering water and again just before the wheat went to the rolls. With this double treatment, the count could be brought down to between 5,000 and 10,000. An improvement over this was to lower the pH of the tempering water with an organic acid such as acetic acid. Still another improvement was to raise the temperature of the tempering water with live steam and then quickly cool.

Flour prepared from good quality wheat was compared with the same wheat stored under aerobic and anaerobic conditions (under nitrogen or carbon dioxide) with 20 percent moisture (Lynch et al. (1962)). The loaves of bread made from the good wheat had a volume of 730 cc. The high-moisture wheat which had spoiled (badly molded) under aerobic conditions had a volume of 515 cc. and wheat with the same moisture content held under anaerobic conditions had a volume of 510 cc. The bread for the two deteriorated wheats were of poor handling properties being very sticky. The flour from the moist wheat stored under anaerobic conditions was believed to have deteriorated as a result of abnormal seed metabolism.

Considerable data on the source of cultures and their identification in cereals and flour may be found in the Manuals of the Aspergilli and Penicillia, especially the older manuals (Thom and Church, 1926; Thom, 1930; Thom and Raper, 1945; and Raper and Thom, 1949).

Wheat Flour--Canada

Castell (1944) examined a number of foods, including cereals for thermophilic bacteria. He found counts of thermophiles ran as high as 13,000 per gram in low-grade wheat flour. He noted that aerobic thermophiles were as high as 12,500,000 in unprocessed cornmeal and to 2,100,000 in untreated soya flour. In some wheat flours, the count was only 80, and in soya flour as low as 630. Some anaerobic spore formers were also found in cereal products but in untreated soya flour, this count was 100,000.

The microflora of five samples of flour in Canada were studied by James and Smith (1948). They confirmed Christensen's finding that a malt-salts-agar gave higher mold counts than media such as Czapek's solution agar. They reported mold counts of 1,140 to 3,960 and bacterial counts of 2,750 to 19,500 per gram of flour. All samples yielded yeasts, thermophilic flat sour spore formers, thermophilic spore formers, and spores of the rope organism.

One of the best papers on microorganisms in flour is that by Thatcher et al. (1953) who studied the microbial and insect content of flour from 50 representative Canadian flour mills. They counted the following types of microorganisms and found the following range in counts: total mesophilic bacterial count, 700-4,516,000; mesophilic spores, 0-3,600; molds, 0-18,500; aerobic thermophilic spores, 0-68; flat-sour spores, 0-32; and anaerobic thermophilic spores, 0-23+. A general relationship appeared to exist between the number of insect fragments and the microbial count except for the thermophilic bacteria. The bleaching of flour reduced the number of fungi and bacteria by about one-half, except for the thermophilic spores. It was found that infected elevator boots were an important source of fungus infection in the mills. In five superior mills and five substandard mills studied intensively, thermophilic spore formers and mesophilic spore formers were found in all samples. The dominant microorganisms in the finished flour were Aspergillus glaucus, Penicillium sp., A. flavus-oryzae group, Flavobacterium, Bacillus sp., Bacillus (rope), Achromobacter, Micrococcus candidus, Alcaligenes fecalis, and Serratia sp. An actinomycete was found in "flour" from boots in the mill.

Wheat Flour--Great Britain

Rather extensive investigations on the microbiology of flour and wheat have been made in Great Britain. Kent-Jones and Amos (1930) and Amos (1931) attempted to plate count bacteria from flour using a wheat-meal agar, but this was not successful because of the precipitation of constituents of the meal after sterilization. The authors used nutrient agar and a 0.5 percent sodium chloride solution to make the flour dilutions. They suggested that the bacterial content of flour from any one mill will greatly vary because of the wheat blend changing, the amount of washing, the length of time the wheat is in the dampening and conditioning bins and the temperature and moisture content while there. Thus, 7 samples taken of patent flour from one mill showed a variation of 5,000 to 10,000 bacteria which grew at 37° C. The lower the grade of the flour, the higher the count. One obtains a higher count with incubation of the counting plates at 20 than at 37° C. They found that in

mills using an average blend of wheat and cleaning and conditioning the wheat in a normal manner, the number of organisms in the patent flour was no more than 20,000 organisms growing at 37° while the straight run flour had no more than 50,000.

They especially investigated the effect of storage of flour on the bacterial counts. About 2 pounds of flour was collected from a mill and placed in cotton bags and placed in the flour storage department. This flour was sampled at various intervals with the following results:

	Temperature of incubation	Days			
		0	7	14	72
Straight run	37	140,000	75,000	55,000	26,000
	20	475,000	160,000	96,000	

It shows that under normal conditions of storage, both the organisms growing at 37 and 20° C. decrease in numbers and that the most important factor affecting reduction in numbers was the moisture content rather than temperature. Kent-Jones and Amos were concerned with the specific organisms present in flour. These were found to be Bacillus mesentericus, B. subtilis, micrococci, coccobacillus, and several other bacteria, not determined as to genus, were also described. The B. mesentericus organisms (rope producers) were universally present in flour. Examination of wheat showed that bacterial counts made at 37° C. ranged from 8,000 to 8,000,000 and at 20° C. from 22,000 to 40,000,000. They indicated that a reduction of 60 percent of the bacteria was obtained by cleaning and washing the wheat before it entered the first break rolls.

Amos and Kent-Jones (1931) reported the numbers of rope bacteria in flour to range from 10 to 160. Even where only 10 spores were present, ropy bread occurred and in other instances a count of as high as 160 gave no rope.

A later paper by Kent-Jones (1937) (mainly concerned with rope) pointed out that mustiness in flour is often associated with a high mold count. Kent-Jones and Amos (1957) give an excellent review of the microbiology of cereals and cereal products.

Fisher et al. (1937) working in England, investigated the changes occurring in four flours over a period of 18 months. Each sample was stored at 12, 16, and 18 percent moisture content and baking tests were made. They stated that all flours improved in baking quality during storage up to a certain point and then deterioration sets in. They noted that after a period of improvement, the flours then deteriorated and then later improved again followed by deterioration. They state that there is little doubt that

chemical changes of flour during storage is due to bacterial and mold action. Furthermore, if flour that is useless for breadmaking because of prolonged storage, is added at the rate of 2 percent to otherwise untreated flour, a marked improving action on baking is observed.

Barton-Wright (1938) studied the changes occurring during storage of two types of flours, one English flour with a moisture content of 16.48 percent, and a Manitoba flour with a moisture content of 14.56 percent. Both were selected as low-grade flours. They were each divided into two portions, one portion moistened until it had a moisture content of 18 percent, the other left with its original moisture content. The highest bacterial count observed was 57,000 per gram. Every 2 weeks, plate counts were made and the pH determined. As expected, the moistened flour showed a more drastic change in pH, dropping from an initial pH of 6.18 to a low of 4.93 at 10 weeks. Their data showed:

Period of storage in weeks	English normal	English moist
	Bacterial count	
0	40,750	40,750
4	40,342	26,400
6	35,000	15,000
8	14,800	6,321
10	14,400	4,200
	Manitoba normal	Manitoba moist
0	37,800	37,800
4	37,600	14,800
6	25,500	4,500
8	14,865	3,900
10	14,150	3,450

In the moist samples, there was a rapid increase in soluble nitrogen and an increase in fungal numbers. In the case of the Manitoba flour, the fungal count was 1,200 and rose to 8,280 in 10 weeks. The normal fungal counts were 1,000 to 2,000 per gram. Over 90 percent of the molds belonged to the genus Penicillium but also present were Aspergillus, Cladosporium, and Botrytis. The Penicillium species were P. brevicompactum, P. patris-mei, P. expansum, and other unidentified isolates. A fair number of yeasts were also found in the moistened sample. The oil content (soluble in ether) was found to decrease rapidly in the moistened samples. In stored moistened samples, the gluten improved in quality due to (1) removal of fats and fatty acids by fungi, and (2) some improving action due to the fungi directly.

In a later paper, Barton-Wright and Tompkins (1940) investigated the fungi in flour, bran, and middlings. They observed that mold growth did not occur on whole meal at 75 percent relative humidity at 20° C.

The work of Kent-Jones and Amos (1930); Barton-Wright (1938); and Soenen and Pinguair (1938) were extensively reviewed by Clifford (1939).

Baker et al. (1958) reported that in England in 1956, much of the wheat was invaded by fungi, especially the dark-colored mycelium of Cladosporium. The season was characterized by cold wet weather during the harvest which promoted mold growth. When this wheat was milled, it led to flour with poor color. The flour showed dark specks consisting of fragments of mycelium or sclerotia, fungus spores or particles of the pericarp carrying dark mycelium.

In 1958 a search was made for bacteria of the Salmonella group in wheat, flour, scourings, offal, and dust, etc., from mills in England (Anon., 1958). Complete failure to find this group of bacteria was reported on the 2,086 samples examined of which 338 were of flour. A second paper in the same journal (Anon., 1958) reported the plate counts of 67 samples of flour and the examination of 115 samples of flour for coliforms. In some instances, the water used to wash the wheat came from heavily contaminated river water. The coliform count was over 1,000 in 2 of 115 samples of flour and in 5 out of the 67 flour samples, the total bacterial count was over 100,000 per gram.

Flour--Other Countries

Thomann (1900) working in Bern, made some of the first bacterial counts of bacteria. He studied 2 flour samples and reported a count of 16,000 microorganisms in wheat rye flour, and 20,000 in a wheat flour. He identified several of the bacteria which he found.

A number of papers have been published in Central Europe which, in part, deal with microorganisms in flour. These are Steinitz (1894), Wolffin (1894), Hoffman (1896), Bloch (1900), Holliger (1902), and Kursteiner (1907), who investigated the bacteria of mill dust.

Semeniuk (1954) in his Table IV, lists a number of species of bacteria found in flour, flour paste, and bread dough. According to Semeniuk (1954), Gordon (1904), found 400,000 to 23,700,000 bacteria per gram of rye and wheat bran.

Gustafson and Parfitt (1933), stated that Papasotiriu (1902) reported Bacterium coli in all white and black bread flours.

Arnoldow (1908) found that with 17 percent moisture, molds appeared in rye flour.

According to Gustafson and Parfitt (1933), Kuhl (1911) reported the presence of Bacillus subtilis in all flours. Kuhl (1941) recommended that grains and flour be dried to 13 percent moisture to prevent mold and bacterial growth. Wright (1916) in Sydney, Australia, studied the cause of mustiness in bread and reported the isolation of Aspergillus and Rhizopus nigricans.

Geilinger (1921) investigated the numbers of fungi in wheat, rye and mixed wheat, and rye flours in 13 Swiss mills. He found the mold count to vary from 1,400-58,000 colonies per gram, and bacterial counts of 5,000 to 92,000, and in 1 sample of wheat and rye flour, found a count of 1,740,000 bacteria. Sartory and Sartory (1926) reported a flour having a musty odor to contain Aspergillus fumigatus.

Gattani (1951) studied the molds in sweet potato and wheat flour in India. The author reported a rich flora of Aspergillus and Rhizopus species in eight samples of sweet potato and wheat flour, and the two mixed. The most common species of Aspergillus were A. glaucus, A. candidus, and A. niger.

Twenty Belgian flours were examined for their mold count by Soenen and Pingnair (1937). They found the mold count to vary from 152 to 19,982 per gram on agar plates and from 0 to 11,640 on gelatin. The bacterial population counted on plates incubated at room temperature ranged from 1,032 to 56,757, while plates incubated at 37° C. showed counts of 11,115 to 70,943 per gram. In a second paper by these authors (1938) they suggest that flour should be sterilized rather than the wheat to obtain flour which would keep. They suggest the use of electricity.

Microorganisms present in 13 French flours were examined by Poisson and Guilbot (1956). The fungus spore counts ranged from 3,000 to 21,000 and consisted of 75 percent Aspergillus (about one-half were A. candidus and the remainder A. glaucus, A. flavus, A. ochraceus, and A. versicolor). Fifteen to twenty percent were Penicillium species. In addition, Cladosporium, Hormodendrum, Alternaria, Mucor racemosus, and M. italianus (Absidia italianus) were present. All samples contained yeasts but their numbers never exceeded 300 per gram. The bacterial count ranged from 10,000 to 84,000. The temperature of storage selected the types of molds. With favorable relative humidities for growth, Penicillia predominated at 4° C., up to 35° C. the Aspergilli, and at higher temperatures, the Mucorineae.

Spicher (1957) reported more thermophilic bacteria were present in wheat flour samples than in wheat.

In Japan, Inagaki and Ikeda (1959) studied the species of molds found in 35 samples of wheat, rice, and soybean flours and corn starch. The Penicillia were represented by 42.2 percent of the isolates and Aspergilli by 29 percent. The more common Penicillium species were P. cyclopium, P. citrinum, P. chrysogenum, P. funiculosum, P. frequentans, while the more common Aspergillus species were A. glaucus, A. versicolor, A. flavus-oryzae, and A. candidus.

According to an unpublished list of literature on flour compiled by S. Stawicki and E. Kaminski of the College of Agriculture, Poznan, Poland, the following Russian and Polish papers deal with, or in part with, the microbiology of flour: Kozmina (1959), Kozmina and Kretowicz (1951), Kretowicz (1945), Kretowicz and Prochorowa (1960), Triswiatski (1951), and Wakar et al. (1958).

Cornmeal

Hiltner (1891) reported the mold count in cornmeal to be as high as 145,000 per gram. The action of molds on the composition of cornmeal was investigated by Street (1904). He found Penicillium and certain bacteria were always present in cornmeal. He noted that cornmeal molded at 25.42 to

38.40 percent moisture and the increase in mold growth resulted in an increase in moisture. Large losses of fat were reported due to mold growth. The Penicillium growth had little effect on the total nitrogen-free extract but Mucor and bacteria caused great losses.

In 1908, Esten and Mason reported the count of bacteria in grain meals to be as high as 3,200,000 per gram. A lactic acid bacterium said to resemble Bacillus bulgaricus was isolated by Heinemann and Hefferan (1909) from cornmeal. They suggested that this microorganism may be common in this meal. Alsberg and Black (1913) studied the biochemistry and toxins of two species of Penicillium from corn.

McHargue (1920) studied the deterioration of cornmeal resulting in a rapid increase in acidity. The degree of acidity corresponds closely to the amount of moisture present. With 12 percent moisture, there is a slow increase in acidity without the product acquiring a rancid or musty odor. The same year, Bailey and Thom (1920) reported that cornmeal had a critical moisture level of 13 percent; above this level spoilage is rapid unless temperature and ventilation conditions are such that growth of microorganisms are inhibited. Geilinger (1921) found a mold count of 3,500 and a bacterial count of 180,000 in meals.

The fungus flora of cornmeal was studied by Thom and Lefevre (1921) seeking the possible cause of meal instability. They reported considerable numbers of fungi and bacteria. The molds most commonly found were Aspergillus flavus, A. tamaria, A. niger, Penicillium oxalicum, P. luteum, Mucor sp., Rhizopus nigricans, and Syncephalastrum. In addition, various yeasts and yeastlike fungi were encountered. Bacteria in fresh meal were represented by the colon-aerogenus group, lactobacilli, aerobic spore formers, and micrococci. These were always present and persisted in the stored product. Above 13 percent moisture, Aspergillus repens began to be an active agent of spoilage. A more detailed paper by these authors (1921) indicates that in 9 commercial samples of cornmeal, the bacterial count as determined on plain agar ranged from 5,000 to 70,000 and from 1,000 to 400,000 molds per gram. Interestingly, freshly milled cornmeal samples showed bacterial counts of 1,000,000 with variation of 600,000 to 1,600,000 with 60 percent of the colonies being acid producers. On wort agar, the mold count averaged 70,000 to 160,000. After storage for a period of only 1 month, 5 samples showed an average count of 108,000 bacterial colonies and 15,000 molds. At 2 months, the count was 12,600 bacteria and 7,600 mold colonies. Aspergillus repens was the fungus, which at levels of 13 percent or above, produced balls of meal loosely held together by mold hyphae. Aspergillus flavus became active only in samples in which the moisture content was 16 percent or above. Yeasts, mucors, and penicillia were present only after levels of 19 percent moisture are obtained. Some bacteria grew when the moisture content of the cornmeal reached a level of 18-20 percent. James et al. (1928) found that moistened cornmeal and cracked corn heated to 62° C. due to the action of microorganisms. Counts in cornmeal moistened to 30 percent moisture and counted at 3 days rose from a count at zero time of 15,000 per gram to as high as 60,000,000. Counts made at 50° C. from the same material rose to as high as 400,000 at the end of 8 days.

Lactobacillus species were isolated from bran, rye meal, cracked corn and wheat, corn flour, and rolled oats by Hunt and Rettger (1930). They noted that grain kept in the laboratory rapidly lose their viable lactobacilli. Most of the lactics from grain failed to ferment lactose.

Rice Flour and Bran

Loeb and Mayne (1952) studied the microflora of rice bran in the United States and found a mold-yeast count of 160,000 colonies per gram, which after 2 weeks storage at 15.1 percent moisture, increased to 1,300,000. The predominating microorganism was a yeast Endomycopsis. Molds found in the bran were Aspergillus flavus-oryzae, A. chevalieri, A. candidus, Mucor sp., Rhizopus sp., and Penicillium sp. Rice bran stored at 33.5 percent moisture with an original bacterial count of 1,500,000 increased by the sixth day to 4,500,000. Aspergillus chevalieri, when inoculated on rice bran, increased the amounts of free fatty acids which did not occur in the uninoculated, sterile controls.

Kurata et al. (1957) studied the microflora of milled rice from the 1954 crop in the southern part of the United States. In an extensive study of the rice kernels from different areas, the amount of internal infection was very low for both bacteria and fungi. In many instances, over 90 percent of the kernels, after only surface washing with sterile water, were free of microorganisms. Actually, when 0.1 percent silver nitrate was used to surface sterilize the kernels, 99.1 percent of them were free from contamination. Similar results were obtained with rice grown in the California area.

Summary

A review of the literature on microorganisms of flour would lead one to the following conclusions. Flour always contains a flora of bacteria and fungi. Under usual conditions, moisture is the most important factor determining spoilage of flour. The fungus flora of flour is well established and is generally limited to Aspergillus and Penicillium, especially the Aspergillus candidus and Aspergillus glaucus group. Considerable contamination of flour with fungi originates within the mill. The types of fungi present are not those found on wheat in the field, but duplicate those forms found in storage. If the moisture level is 12 percent or less, no growth of microorganisms will occur. As flour is stored with a low-moisture content, the number of viable microorganisms decreases fairly rapidly. Except for the rope organism, the bacterial flora of flour and the source of these organisms is poorly known. The bacterial count is greater than the mold count. Special media are required for the enumeration of molds and bacteria.

Probably the most important problem of flour microbiology is the identification and the source of the bacterial population. It is our opinion that this population may be as specialized as the fungus flora.

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PART II.--MICROBIOLOGICAL METHODS USED AT THE NORTHERN LABORATORY FOR EXAMINATION OF FLOUR

A recent meeting between representatives of the Millers' National Federation and the Northern Laboratory brought to light the need for new and greater research efforts in the area of microbiological control in flour. The growing interest in this area has resulted largely from the ever-increasing wave of new refrigerated and frozen convenience foods now reaching the market. Flour to be used in the manufacture of uncooked refrigerated canned biscuits, frozen fruit pies, frozen meat pies, and the like, must have a low microbial count to be acceptable. Likewise, manufacturers of baby foods, canned foods, and other convenience foods utilizing flour are beginning to specify flours of low microbial count. Some mill customers, for example, are now specifying a maximal count of 500 per gram, a figure which at present seems unrealistic and perhaps unattainable by ordinary milling procedures. It is becoming increasingly important, therefore, that the milling industry know more about the microbiological condition of its products.

In order to establish the present status of U.S. flours, it was decided that our research activities should start with a survey of general use flours produced by various mills throughout the country. This would provide background information essential for future work. To accomplish this end, six geographical areas representing a cross section of the nation's major wheat producing areas were chosen for the study. These areas include the following:

1. Kansas-Nebraska area: hard red winter wheats
2. Montana-North Dakota area: hard red spring wheats

3. Michigan-Indiana area: soft white and red winter wheats
4. Southeastern U.S.: soft red winter wheats
5. Texas-Oklahoma area: hard red winter wheats
6. Pacific Northwest: white club and soft white wheats

Arrangements were made through the Millers' National Federation to have 10 different mills in the Kansas-Nebraska area, the first area to be studied, collect and send samples of patent and first-clear flour to our Laboratory. An attempt was made to select mills representing as wide a spread of milling practices as possible. In order to obtain representative results and avoid abnormally high or low microbial counts, two sets of samples were collected 2 weeks apart from each of the participating mills. Specimens were collected in either new paper bags or in special cloth sample bags in 1 to 2 pound quantities by mill personnel and sent to Northern Regional Research Laboratory for examination.

Analyses have included gross counts of bacteria (aerobic and anaerobic), and fungi (molds and yeasts), and differential counts of thermophiles, psychrophiles, osmophiles (bacteria and fungi), coliforms, fecal streptococci, salmonellae, food-poisoning staphylococci, thermophilic spores (total aerobic, flat-sour, and gas-producing anaerobic), and rope spores. The methods used were, for the most part, those outlined in the latest editions of Recommended Methods for the Microbiological Examination of Foods (American Public Health Association, 1958), and Cereal Laboratory Methods (American Association of Cereal Chemists, 1962). Although the methods described in both manuals were essentially the same, it was necessary to use both since, in some instances, one outlined procedures not found in the other.

The procedure for making microbial counts using the agar plate method (Standard Methods for the Examination of Dairy Products, 1960) is shown in the flowsheet in Figure 1. After thoroughly mixing the sample to obtain an even distribution of the microflora, 11 grams were aseptically weighed in a sterile aluminum weighing scoop (30 ml. capacity) and transferred to a 6 ounce rubber-stoppered dilution bottle containing 99 ml. of sterile 0.1 percent peptone water (Straka and Stokes, 1957) and approximately 10 grams of sterile sand (dispersing agent). The bottle was shaken vigorously for 2 minutes and allowed to stand for a minute or so to allow the foam to subside. Higher serial dilutions were then prepared from this primary dilution (1:10), again using dilution blanks with sand, and plates were prepared in duplicate from the appropriate dilutions.

Total Bacteria

An estimate of the total aerobic bacterial population was determined by preparing pour plates with Plate Count Agar (PCA, Difco) containing 100 p.p.m. cycloheximide (Acti-dione) (Pepper and Kiesling, 1963) to inhibit fungal growth. Preliminary experiments had shown that cycloheximide in this concentration had little or no effect on bacterial growth. The plates were

incubated at 32° C. for 3 days. In most instances the colonies were counted with a dark-field Quebec colony counter. However, when it was necessary to count plates of low dilution having a dense background of flour particles, a stereoscopic microscope was used at magnifications of 12X to 36X to distinguish small subsurface colonies from such particles.

Total anaerobic bacteria were determined as described above except that the plates were incubated under anaerobic conditions for 3 days at 32° C. A number of methods for achieving anaerobiosis are described in the Manual of Microbiological Methods (Society of American Bacteriologists, 1957). A gas-replacement system employing nitrogen as the inert gas proved quite satisfactory in our Laboratory.

Thermophilic Bacteria

Total counts of aerobic and anaerobic thermophilic bacteria were made in the same manner as the mesophilic counts described above except that the plates were incubated at 55° C. for 48 hours.

Psychrophilic Bacteria

Numbers of psychrophilic bacteria were determined according to the method outlined in Cereal Laboratory Methods (American Association of Cereal Chemists, 1962). The use of 100 p.p.m. cycloheximide in the plating medium was the only modification in procedure. The plates were incubated at 5° C. for 7 days as recommended.

Molds and Yeasts

To obtain an estimate of the total number of molds and yeasts present in flour, duplicate plates were poured with a yeast extract agar (0.4 percent yeast extract, 0.4 percent dextrose, 1.0 percent malt extract, and 1.5 percent agar) containing 30 p.p.m. tetracycline HCl (Achromycin) to selectively inhibit bacterial growth. The filter-sterilized antibiotic was added to the melted agar prior to pouring. Incubation was at 28° C. for 5 days. In most instances the colonies were counted both with the unaided eye and with the stereoscopic microscope. Magnification was frequently required since, as Christensen (1946) has already pointed out, subsurface colonies of certain molds grow quite slowly and often are not visible to the naked eye even after 6 or 7 days of incubation. As with cycloheximide, preliminary tests had shown that tetracycline, at a concentration of 30 p.p.m., had no effect on the fungal population.

Osmophilic Counts

Although no standard procedure for determining numbers of osmophilic microorganisms in flour is described in the AACC or APHA books referred to previously, a quantitative estimation of these organisms was made using yeast extract agar (YXT) containing 20 percent sucrose. To enumerate osmophilic bacteria, pour plates were prepared with the modified YXT agar to which

100 p.p.m cycloheximide had been added, and incubated at 32° C. for 48 hours. From the same serial dilutions, a second set of plates were poured with the same basal medium containing 30 p.p.m. Achromycin to obtain an osmophilic count of molds and yeasts. Colonies were counted both macro- and microscopically after 5 days at 28° C.

Actinomycete Count

An estimate of the actinomycete population was made by counting typical colonies appearing on the plates prepared for the enumeration of total aerobic bacteria after the plates had remained at room temperature for an additional 11 days giving a total incubation period of 14 days. The method proved unsatisfactory primarily because, in many instances, it was not possible to differentiate between bacterial and actinomycete subsurface colonies on the basis of colonial morphology. Confirmation of suspect colonies therefore required microscopic examination of stained slide preparations, a procedure far too time consuming for routine counting. Efforts to develop a better method are currently being made at this Laboratory.

Bacterial Spores, Potential Pathogens, and Bacteria of Sanitary Significance

Counts of thermophilic spores, food-poisoning staphylococci, salmonellae, coliforms, and fecal streptococci were made according to the methods outlined in Cereal Laboratory Methods (American Association of Cereal Chemists, 1962). For the determination of rope spores, the method described in Recommended Methods for the Microbiological Examination of Foods was preferred.

For Examination of Refrigerated Flour Products

In addition to the flour survey, the microbiology of a number of spoiled refrigerated flour products (canned biscuits, dinner rolls, etc.) has been investigated. Samples representing a variety of refrigerated dough products were purchased from local supermarkets and brought immediately to the Laboratory for examination. An attempt was made to obtain samples which were either spoiled or had exceeded their expiration date. Samples showing no external evidence of spoilage were held to 4 to 5° C. until spoilage became evident. This was almost always manifested by varying degrees of positive pressure in the container accompanied by a sticky exudate. Frequently containers were blown, resulting in dough extrusion through the opening.

A flowsheet of the procedure used in making the various microbiological analyses is shown in Figure 2. First, the can was wiped off thoroughly with a clean rag moistened with 70 percent ethyl alcohol. With blown containers, exposed dough was carefully trimmed away with a sterile knife or spatula to avoid adding extraneous microorganisms to the product. The label was then stripped off and the container was sanitized again, giving special attention to the areas about the seams. This eliminated gross external contamination. Taking aseptic precautions, all of the dough was removed from the container, placed in a sterile blendor cup, and blended for 1 to 2 minutes or until homogenized. Fifty grams of the blended material were weighed in a sterile aluminum

weighing scoop and transferred quickly to a second sterile blendor cup. To this, 450 ml. of sterile 0.1 percent peptone water were added using part of the diluent to wash residual material from the spatula and scoop. The contents were blended for 3 minutes at low speed, taking care to avoid overheating the material. The resulting mixture constituted the primary dilution (1:10) from which appropriate decimal dilutions were prepared, again using dilution blanks containing 99 ml. of 0.1 percent peptone water and approximately 10 grams of sand. Dilutions were selected to give from 30 to 300 colonies per plate, and plates were prepared in duplicate.

Total Bacteria

To determine the total bacterial population, pour plates were prepared with APT Agar (Baltimore Biological Laboratory) containing 100 p.p.m. cycloheximide and incubated at 32° C. for 3 days. The APT medium was used in preference to Plate Count Agar (PCA) because: (1) preliminary experiments showed that it consistently gave higher counts than PCA, and (2) colonies of the predominant bacterial types present were much larger and hence easier to count and isolate from than the pinpoint colonies that developed on PCA.

Lactic Acid Bacteria

The lactic acid bacteria were enumerated using Sucrose-Tween Agar, a selective medium recommended in a technical bulletin (Bacteriological Control of Refrigerated Biscuit Packing Operations, 1959) made available to us by the American Can Company. The medium is prepared as follows:

Tryptone	10	g.
Yeast extract	3	g.
Dextrose	4	g.
Sucrose*	20	g.
Cysteine hydrochloride	0.001	g. (approx.)
Tween 80-10 percent solution	2	ml.
Sorbic acid	1.3	g.
Agar	20	g.
Distilled water	1,000	ml.

Adjust pH to 5.5 - 5.8

Dispense and sterilize at 121° C. for 12 to 15 minutes

* Ordinary cane sugar may be used.

The plates were incubated at 32° C. for 48 hours. With longer incubation, the large viscous colonies which usually develop tend to run together making it difficult, if not impossible, to get an accurate count.

Psychrophiles and Fungi

Fungi (molds and yeasts) and psychrophilic bacteria were determined by the methods described previously for the examination of flour.

Preliminary Counts

Preliminary studies of four patent and three first-clear flours have shown that total aerobic bacterial counts range from 1,300 to 8,700 per gram in the patent flours and 3,200 to 14,000 in the first-clear flour, while fungal counts vary from 280 to 2,400 and 290 to 4,200 per gram, respectively. Although a number of refrigerated dough samples have been examined, the data available are not sufficient for presentation at this time and will be reported in a later paper.

Isolation, Purification, and Identification of Microorganisms from Flour and Refrigerated Flour Products

In order to survey the microflora of the flour and refrigerated dough samples qualitatively as well as quantitatively, it was necessary to isolate, purify, and identify the organisms developing on the various plating media. With the flour samples, bacteria and actinomycetes were isolated from the plates used for enumerating total aerobic bacteria (PCA); the fungi were isolated from the plate cultures used to count total molds and yeasts (YXT agar). Bacterial cultures from the dough samples were obtained by subculturing the colonies appearing on the APT Agar plates used for counting total bacteria, while fungal isolates were taken from the YXT agar plates. An accurate appraisal of the relative abundance of each species present in the sample required that each colony present on or in the agar medium be subcultured and identified. This was possible with the molds, yeasts, and actinomycetes where colony numbers rarely exceeded 30 to 35 per plate, but was not feasible with the bacteria where the number of colonies was usually much greater than this. It was decided, therefore, that a reasonably accurate picture of the taxonomic distribution of the bacteria could be obtained by subculturing and identifying a representative fraction of the total number of colonies present. This was done as follows: with each sample, one of the plates used for the colony count was selected and a sector containing 25 to 30 well-separated colonies was delineated on the bottom of the dish with a wax pencil. Each colony within the sector was picked into trypticase soy broth (B.B.L.) and incubated at 32° C. The cultures were purified by streaking growth from the broth culture onto trypticase soy agar (B.B.L.) plates. Once purified, the cultures were maintained on agar slants (APT or trypticase soy) at 4° C. Actinomycete and fungal colonies were subcultured on slants of an asparagine dextrose agar (ADA) having the following formula:

Beef extract	2.0 g.
K_2HPO_4	0.5 g.
Asparagine	0.5 g.
Dextrose	10.0 g.
Agar	17.0 g.
Distilled water	1,000 ml.

Adjust to pH 6.8 - 7.0

Among the molds so far identified, those belonging to the Aspergillus glaucus and A. candidus groups have been predominant in most of the flour and dough samples. In some instances, species of Penicillium not yet identified have been the prevalent molds. Aspergillus sydowi, A. fumigatus, A. flavus, A. versicolor, A. terreus, Rhizopus arrhizus, Mucor alternans, Absidia ramosa, Paecilomyces varioti, and species of Fusarium, Alternaria, Cladosporium, and Sporotrichum were encountered far less frequently. Isolates of bacteria and yeasts have not been identified as yet. A more complete taxonomic appraisal will be reported in a later paper.

Summary

The preliminary findings of microorganisms in flour from the Kansas-Nebraska area shows that the bacterial count in patent flours varied from 1,300 to 8,700 bacteria and 280 to 2,400 fungi, and in first clears from 3,200 to 14,000 bacteria and 290 to 4,200 fungi.

These counts are similar to those reported in the literature, except the bacterial counts are rather low. This may be due to the age of the wheat being milled, and the age of the flour.

Types of molds are the same as those reported by others--namely, the Aspergillus glaucus group, A. candidus, and species of Penicillium.

We have not examined a great many flours, but those that we have, have been examined intensively. At least 20 different counts have been made on each sample. Interestingly, we have not encountered a single Salmonella or Staphylococcus.

The causal agents in deterioration of refrigerated flour products are bacterial in origin but there is no evidence as yet that these bacteria originate from the flour.

From our preliminary studies, flour is an excellent product microbiologically.

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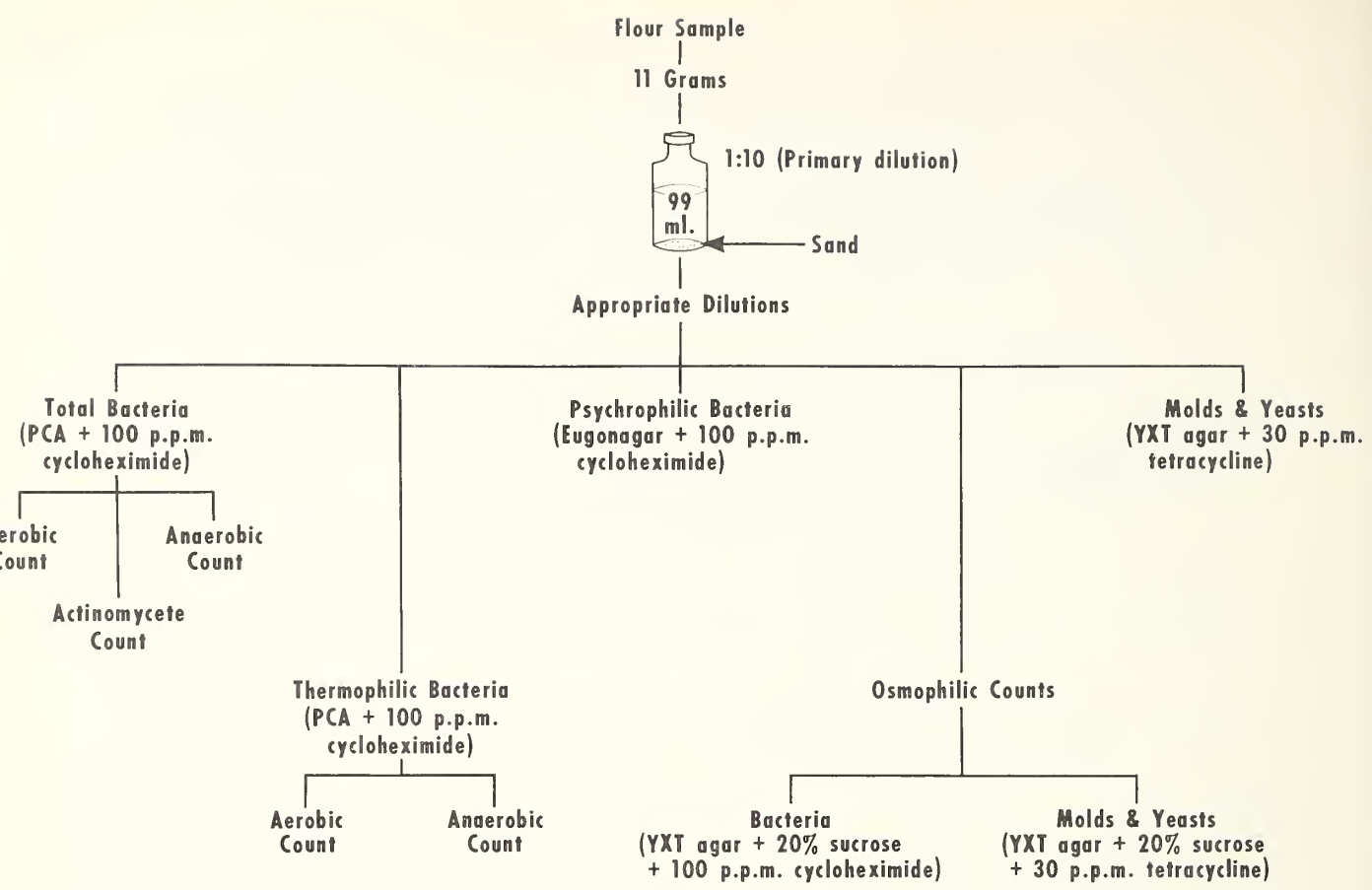
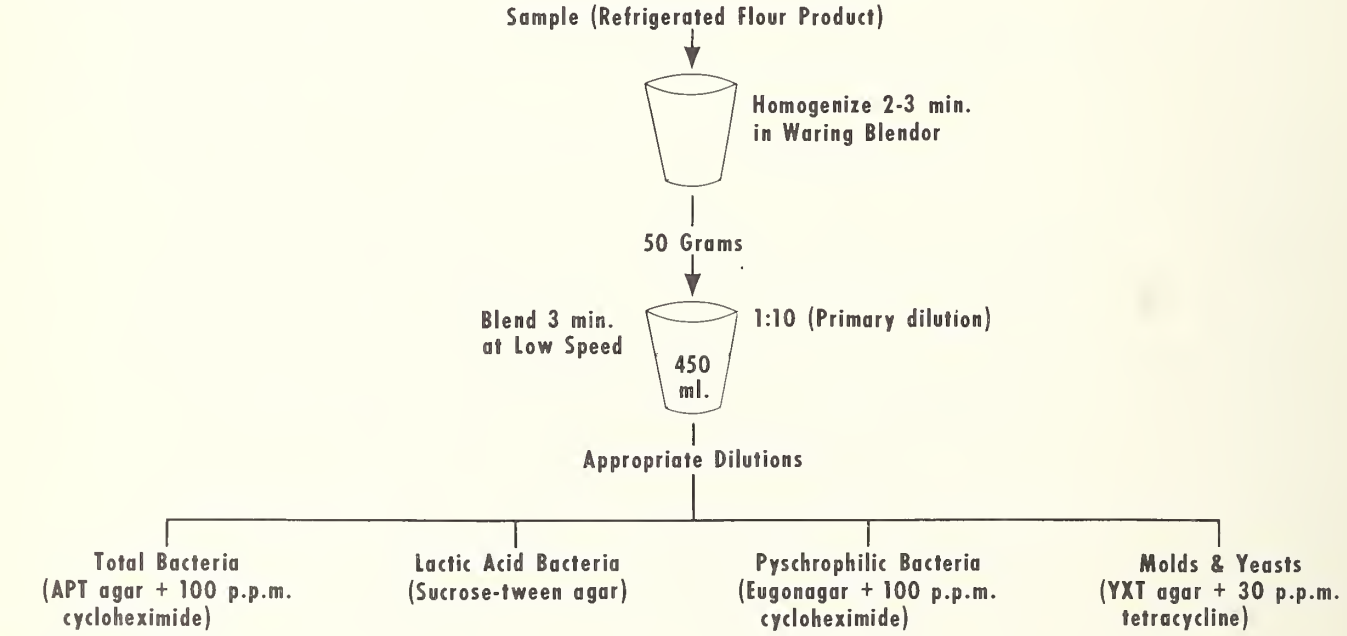

Flour Sample
11 Grams
1:10 (Primary dilution)
99 ml.
Sand
Appropriate Dilutions
Total Bacteria (PCA + 100 p.p.m. cycloheximide)
erobic Count
Anaerobic Count
Actinomycete Count
Psychrophilic Bacteria (Eugonagar + 100 p.p.m. cycloheximide)
Molds & Yeasts (YXT agar + 30 p.p.m. tetracycline)
Thermophilic Bacteria (PCA + 100 p.p.m. cycloheximide)
Aerobic Count
Anaerobic Count
Osmophilic Counts
Bacteria (YXT agar + 20% sucrose + 100 p.p.m. cycloheximide)
Molds & Yeasts (YXT agar + 20% sucrose + 30 p.p.m. tetracycline)

ig. 1


Sample (Refrigerated Flour Product)
Homogenize 2-3 min. in Waring Blendor
50 Grams
Blend 3 min. at Low Speed
1:10 (Primary dilution)
450 ml.
Appropriate Dilutions
Total Bacteria (APT agar + 100 p.p.m. cycloheximide)
Lactic Acid Bacteria (Sucrose-tween agar)
Pyschrophilic Bacteria (Eugonagar + 100 p.p.m. cycloheximide)
Molds & Yeasts (YXT agar + 30 p.p.m. tetracycline)

ig. 2

SOLUBLE PROTEINS IN FLOUR IMPORTANT TO BAKING PROPERTIES

D. K. Mecham, Head, Functional Properties Investigations,
Cereals Laboratory, Western Regional Research Laboratory,
USDA, Albany, California

The term "soluble proteins" has been used generally to include all non-gluten proteins of wheat flour. I am sure you recognize that this is hardly a complete definition since it depends on the definition of gluten proteins, but it does indicate the manner in which the soluble proteins are usually obtained. In other words, when gluten is collected by kneading a dough in water to wash out the starch, and the starch is allowed to settle out of the wash water, any protein that has dissolved and remains in the wash water is "soluble" or "non-gluten" protein. Other materials are present too, of course - for example, sugars, salts, and gumlike carbohydrates, along with the proteins. The soluble proteins also can be obtained by direct extraction of flour without washing out gluten. The distinction between soluble and gluten proteins that I have just given has been a useful one; but as we'll see later it is no longer adequate.

You probably have all heard wet gluten described as a rubbery, extensible mass, which has an obvious, direct relationship to the elastic and extensible properties of doughs and therefore to their baking performance. In contrast to gluten, the soluble proteins show no such obvious relationship - in water or salt solutions they just dissolve, more or less easily. Furthermore, the total amount of soluble protein is usually about one-fifth the amount of gluten. With only that much information available, one might begin to question why the soluble proteins deserve attention if we are concerned with the baking performance of flours, and to suspect that if they do have an influence it may be difficult to demonstrate and explain.

However, there are at least two compelling arguments for work on the soluble proteins. One is a negative one; work on gluten has not been successful to a satisfactory degree in accounting for baking differences among flours. If it had been, the solubles probably would have received even less attention than they have. Since differences in baking performance have not been related solely to differences in glutens, the solubles (and starches) seem likely to be involved. A second, more positive argument is that both bread and cake baking experiments have been reported in which, by omission of soluble proteins or by substitution between flours, the solubles have been shown to be responsible for differences in baking performance. Because these observations are the principal practical justification for research on the soluble proteins in relation to baking, I thought it would be worthwhile to review them for you.

Perhaps the clearest examples to cite are the results obtained by Karl Finney at the Hard Winter Wheat Quality Laboratory in Manhattan, Kansas, and published about 20 years ago. He separated gluten and starch and recovered all the water-soluble materials from three different flours; and then baked bread from the recombined fractions of each flour and also with gluten and starch without the solubles. Omission of the solubles resulted in a definite decrease in loaf volume with two of the flours, but had no effect with a third.

Later in our laboratory we carried out some similar work with five widely different flours. We added the five different solubles to two different glutens, and also used one flour's solubles with the five different glutens. The loaf volumes obtained showed that differences had to be attributed to both glutens and solubles.

Further work was done to determine that the proteins rather than other components in the solubles were responsible for most of the effects observed. Some of the results are shown in Table 1; the loaf volumes given are for microloaves containing 30-gram flour fractions. Here we are using the term "albumin" to designate all the water-soluble proteins recovered from the total water-soluble materials; that is, the sugars, salts, etc., present in the gluten wash water had been removed. As is shown, the albumins alone produced a large response - 29 cubic centimeters. That this was truly a response to the added albumins is shown by the lack of response when the albumins were heated, causing them to lose their native properties and to become insoluble in much the same way egg white proteins do. The total solubles gave a somewhat larger response than the albumins alone, but the major portion was due to albumins. Also, heating the total solubles again showed that the presence of the native, undamaged albumins was required for the large response in loaf volume. We also tried additions of other proteins, e.g., some water-soluble albumins such as egg albumin and some water-insoluble proteins such as casein, as well as additional gliadin and gluten, but we found nothing that approached the flour albumins in effectiveness.

TABLE 1.--Loaf volume responses of gluten-starch doughs to albumins and total solubles

Addition	Loaf volume
None	157 cc.
Albumin	186
Heated albumin	154
Total solubles	198
Heated total solubles	171

Similar but more elaborate work with cake flours has been done more recently by Donelson and Wilson at the Federal Soft Wheat Quality Laboratory in Wooster, Ohio. They varied the concentrations of their recombined fractions and also interchanged fractions from good and poor cake flours. Although other fractions had larger effects, a significant effect of the water-soluble components again was observed. The extent of their effect varied with the composition (in terms of the proportions of other fractions) of the remainder of the reconstituted flour.

There are a few reports of work in which the addition of solubles to gluten and starch did not give a response in bread baking, for example, recent work by Kulp and Bechtel at the American Institute of Baking. While the reasons are not known exactly, this variation in results is not too disturbing because of differences in both separation and baking procedures used by different workers.

If it does raise some doubts that the baking experiments demonstrate the importance of solubles, it seems only fair to give a counter-argument. Recent improvements in methods and techniques for characterizing the wheat proteins, and particularly gluten, leave no doubt that all the gluten proteins used in all the baking experiments I have referred to contained appreciable amounts of nongluten components that were not washed out. That is, we know now that the gluten-washing technique alone just cannot make a complete separation. The presence of unremoved solubles in the gluten in the baking work then means that some of the effects of the solubles had already been exerted even in the so-called gluten-starch doughs. The addition of more solubles then still had some effect in most cases, but the total effect of the soluble proteins must have been underestimated. Only the effects of the <u>added</u> solubles were observed.

I think we have discussed this aspect about as far as is profitable, and we should return to a more complete description of the soluble proteins. As with every other class of compounds in flour, the soluble proteins have been found to be more complex as the techniques for investigating them have improved. There now appear to be at least a dozen protein components in the "solubles." The easiest way to demonstrate this is by gel electrophoresis, in which proteins are migrated through a gel by application of an electrical potential. The gel can be prepared from any one of several materials that hold a high proportion of water - gelatinized starch has been used extensively. Under these conditions, the rates at which the separate proteins in a mixture move depend both on the electrical charges their molecules carry and on their molecular size and shape relative to the pore size in the gel. With both charge and size playing a part, the procedure is an extremely effective one for separating proteins. After a separation has been made, the proteins can be stained with a dye and the gel dried. The number of separate stained bands provides an estimate of the minimum number of protein components in the mixture applied.

Two such gel strips are shown in Figure 1. The top one shows results with material extracted from flour with a dilute salt solution, that is, with soluble proteins. Since each band or stripe represents at least one component, the material clearly does not contain a simple protein mixture. Considerable contrast is lost in the photography and so I don't know how many you can count, but on the gel itself one has no trouble in counting 10 bands. I should have pointed out that the extracted material was dissolved in the Al lactate buffer that Jones, Taylor, and Senti of NU introduced and that has been so useful in studies of wheat proteins. The other stripe in the figure shows the results when the same procedure was applied to gluten washed out of the same flour and also dissolved in Al lactate buffer. It is included to illustrate the point covered earlier concerning the presence of soluble proteins in gluten. Under the conditions used here, the gluten proteins move more slowly than the solubles; all the bands to the right of this point are gluten bands. The others are nongluten and match up with about six of the soluble components in the extract. You can see that the gluten obtained in the usual way retained a considerable amount of nongluten protein.

Obviously we have to revise our definition of "nongluten" or "soluble" proteins and base it on something other than a description of gluten washing. Without going into specific details, we can say that the gluten and nongluten proteins can be distinguished by their electrophoretic behavior and classify any particular wheat protein we may have in that way.

To some extent, we can be more specific about their differences. The nongluten proteins are made up of smaller and probably more compact molecules. Their amino-acid composition - that is, the proportions of the various protein subunits they contain - also is quite different. The nongluten proteins contain less glutamic acid and proline, and in fact are less "unusual" in amino-acid composition than the gluten proteins. The amino-acid composition of the nongluten proteins also accounts basically for their higher electrophoretic mobility even in the absence of the sieving effect of a gel.

Probably the feature of amino-acid composition of most interest is the lysine content. From a nutritional standpoint, the first question always raised about flour as a protein source is its low lysine content. It is worth noting therefore that the soluble proteins contain much more lysine than does gluten. Under conditions where flour or other cereals would make up a large proportion of the diet, the soluble proteins would be nutritionally valuable, and consideration of ways to increase their proportion would be worthwhile. Because milling byproducts contain a much higher proportion of nongluten proteins than flour does, they are a potential large source, and work is in progress to develop special high-value products from this source, as Dr. Kohler mentioned yesterday.

With the rather marked differences in size, shape, and amino-acid composition of the gluten and nongluten proteins, the association of them referred to earlier is interesting just from the standpoint of the properties of the proteins that make it happen. Some recent work in Australia makes it seem even more unusual because that work has shown fairly convincingly that the gluten and soluble proteins occur in separate locations within the

endosperm cells of the kernel. The association then would seem to occur during dough mixing and washing of gluten.

As you saw earlier, the soluble proteins certainly consist of many components, despite their relatively small total amount. To account for the effects of the soluble proteins in baking, then, it seems likely that one should look for some fairly specific changes which soluble components can produce in the basic structure of gluten or dough. Nonspecific effects need not be ruled out completely, as some nonspecific ones can be suggested. For example, the soluble proteins are easier in general to denature or coagulate by heat than the gluten proteins, and this might affect baking performance in some products. The various soluble proteins also may act in a sense as "plasticizers" of gluten, as some materials are used in synthetic plastics to make them more flexible. Such general effects seem likely to be quite similar in all flours, so that they would not account for differences in baking performance among flours.

In contrast, from currently available information at least three quite different ways can be suggested for soluble proteins to affect dough behavior markedly, while at the same time ample opportunity is provided for wide variations in the effects produced. The three are changes brought about by enzyme action, by oxidation, and by participation in disulfide-sulfhydryl interchanges; and each will be considered.

The most obvious way in which a soluble protein could exert an effect out of proportion to its amount is through enzymatic activity, since the property of promoting reactions between other compounds without itself being changed is the essential feature of an enzyme. Since Dr. Johnson probably will give you considerable information on the proteases and amylases which modify proteins and starch, I have chosen to use one of a different class, the lipoxidases, as an example of how they may be involved in baking performance by an indirect route. The lipoxidase in flour is water-extractable, but it catalyzes the oxidation of fatty material, specifically of certain unsaturated free fatty acids, during dough mixing by transferring oxygen to them. This is indicated in Figure 2 on the top lines. The products, the hydroperoxides, then can oxidize the sulfur-containing, reactive sulfhydryl groups in flour proteins as indicated on the next line. The latter change, and perhaps the oxidation of the fatty acids as well, would be expected to modify the physical properties of dough. The bottom section of the figure was included to give some idea why it is not easy to evaluate the possible significance of lipoxidase. As shown, oxygen in dough can be used up in direct oxidation of sulfhydryl groups, bypassing the lipoxidase. Either way, sulfhydryls are oxidized but the oxidation products probably are different and may have quite different effects on dough properties. Various other enzymes are present in the soluble proteins. In most cases, but with the amylases certainly excepted, their significance to baking has not been satisfactorily evaluated because of lack of pure preparations and information on their properties.

A second way in which soluble proteins may be involved in, and important to, baking performance is in their reaction with chemical oxidizing agents. Water extracts alone or water extracts added to gluten dispersions have been observed to gel when treated with potassium bromate or other oxidizing agents as used for artificially "maturing" flour and doughs. This marked change in flow properties led to the suggestion that the components involved were those that are responsible for changes in doughs when artificially matured. The components involved have not been identified completely. Earlier reports indicated that carbohydrate material was responsible for the gelation, but more recent work in Switzerland has shown that protein-carbohydrate combinations are involved. With completely protein-free materials, gels were not obtained. Because no other natural systems with quite this sort of gelling reaction are known, the mechanism is of general interest. When it is understood, the significance of the components involved and of the gel formation to baking performance and maturing effects will certainly be investigated.

A third possibility to relate soluble proteins to dough properties is through sulfhydryl-disulfide interchange reactions. These reactions are very popular right now among those of us interested in dough properties; I suspect this is partly because they provide a mechanism that can be suggested to account for almost any sort of change in properties. In Figure 3, we see a schematic representation of one way such interchanges might occur.

Each zigzag line represents a gluten protein unit. The four are joined together by disulfide bonds (pointed broad lines to represent the two sulfur atoms involved in each bond). In this kind of arrangement, extended on and repeated many times, the whole system of large and small networks would have a high viscosity and some degree of elasticity. Also on the figure are two soluble protein molecules represented as much shorter, but broader, molecules; on each one is a sulfhydryl group - again with a sulfur atom but here with small dot to represent hydrogen.

If disulfide-sulfhydryl interchanges occur, possibly during dough mixing, the system is changed to that shown on the bottom of the figure. Now the two soluble protein molecules are joined to the gluten molecule by disulfide bonds, the gluten network has been split in half as indicated by the dotted line, and the part of the gluten network below has two sulfhydryl groups that are free to react all over again - either somewhere else or just to reverse the whole procedure. But to emphasize the feature that seems so attractive, the gluten fragment shown on the bottom, now with the sulfhydryl groups, could equally well interchange one sulfhydryl with a disulfide in each of two separate small networks and so build up a much bigger network, and begin to change physical properties very markedly.

As the diagram is drawn, the soluble proteins are the initiators of the process. This was done because the soluble proteins contain a higher proportion of sulfhydryl groups than the gluten proteins, and those in the solubles are also more reactive. Since so many possibilities exist if such reactions do occur, we hardly know what to expect; the direction they take might well depend very much on conditions in the dough. One example can be cited to

indicate that something of this nature may be important. Some British workers have found that in flour, some beta-amylase is attached to glutenin by disulfide bonds, and in this state is inactive. If a sulfhydryl compound is added, the beta-amylase is released and is active. This would be the reverse of the binding of solubles shown in Figure 3.

The three possibilities I have suggested as mechanisms by which nongluten proteins could modify the baking performance of flours are not mutually exclusive. It may be that all play a part, and others may too. Whatever the mechanisms may prove to be, the baking observations that were reviewed and our present knowledge of the properties of nongluten proteins - particularly their tenacious association with gluten as usually prepared - show their importance. We need to acquire much more information about them if we are to establish the bases on which differences in baking characteristics rest. In our laboratory two lines of work are underway. In contract work with Washington State University, methods for rapid separation and measurement of the amounts of gluten and nongluten proteins in flours are being developed. These methods will provide means for comparing composition with baking performance of large numbers of flours. At the Western Laboratory, the actual isolation of working quantities of the various nongluten proteins is being carried out. With such materials available, their properties can be determined, and direct observations of their effects on baking performance can be made when they are added to doughs. In these ways we expect to be able to evaluate more precisely the significance of nongluten proteins to baking performance. The ultimate objectives of the work are to provide the foundation information for development of better quality tests for wheat and flour, better ways to control properties of products made from wheat, and better products from wheat with which to enlarge the total markets for this important crop.

Fig. 1

Oxygen + Flour fatty acids $\xrightarrow[\text{of flour}]{\text{Lipoxidase}}$ Fatty acid hydroperoxides

Fatty acid hydroperoxides + Flour protein sulfhydryl groups → Loss of sulfhydryls (products unknown)

Oxygen + Flour protein sulfhydryl groups → Loss of sulfhydryls (products partially known)

Fig. 2

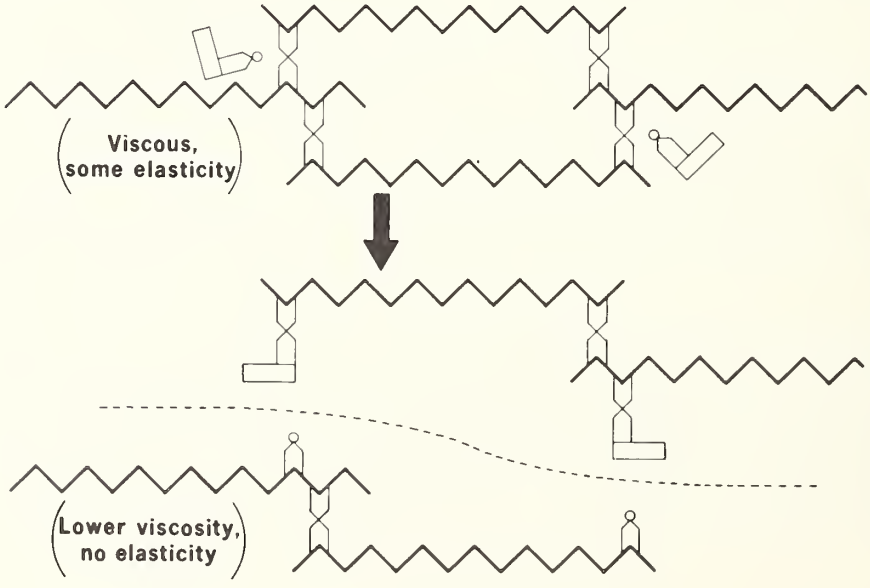


Fig. 3

WHEAT FOOD PRODUCTS FOR SPECIALIZED MARKETS

Robert L. Olson, Assistant Director
Western Utilization Research and Development Division, USDA,
Albany, California

Introduction

One of the objectives of utilization research is to increase markets for wheat by developing new products. Finding new products is a challenge because wheat has been so long associated with man that he has explored its food possibilities in great detail. But, new product development is also an opportunity because wheat is an exceptional food, being highly nutritious and adaptable to wide variation.

Man's association with wheat is traced back some 8,000 years through the remains of kernels found in ancient villages in Egypt and the Near East. By then there were already advanced types of emmer and einkorn, so we know that wheat must have been evolving from wild grasses for thousands of years before that. Man and wheat were together so long that countless accidental discoveries and trials had led to the complex procedures of breadmaking and brewing by the time of the early Egyptian civilization. Early man could not believe such products were within the reach of his own inventive genius, so gods were worshipped as the originators. Our remote ancestors did not realize what accomplishments were possible by the slow process of evolution.

Now we understand the possibilities of long gestation. In fact we would not expect to find anything new to develop if it were not for the special circumstances of our time.

Ancient man made very complicated food products with only minor control over natural forces. He did not understand these forces. However, in a few generations we have acquired considerable understanding and control over them. We now expect to develop new products by applying our scientific understanding. We no longer depend upon the long gestation period of accidental discoveries and evolutionary developments.

Exacting control can be exercised over temperature, pressure, and humidity. The components of wheat can be physically separated and chemically modified. This new-found understanding can be used to create food products that will fit any specification that our imaginations may bring to us.

Our food product research is now the systematic application of knowledge to convert wheat into a range of foods that will meet specialized market requirements.

We are strong in the belief that new markets are developing fast and that we can anticipate them. New products will move into these markets. If they are not wheat products they will be other foodstuffs and wheat markets will continue their half-century loss in per capita consumption.

Today I will identify some of the markets we think might be exploited to benefit wheat utilization and describe the objectives and progress of several product developments now under study.

Specialized Food Markets

I will discuss four specialized markets for product development through utilization research: (1) The commercial market for variety and convenience foods; (2) the commercial market for protein-rich foods; (3) the concessional market; and (4) the emergency food supply. New products for any of these markets may have some application in the others.

The Commercial Market for Variety and Convenience Foods

A commercial market for variety and convenience foods has been growing in recent years and is replacing the cook's skill and virtuosity. Variety is provided by different packages instead of by imaginative use of the cookbook. Convenience foods reduce labor costs and control portion sizes in restaurants; they support the flourishing vending machines; and they complicate the grocery inventory with 6,000 to 7,500 items to keep in stock. Many of the items sold depend upon momentary decisions as customers pass the grocery shelves.

To maintain its share of this market, wheat must hold its share of the shelf space. A continuing flow of new convenience wheat products is required.

The great versatility of wheat is the strong point we would exploit. Products are needed that tempt the palate in many different forms so they can be used in series for a long time without repetition. Products should be either ready-to-serve or very convenient to prepare, being neither time-consuming nor difficult. Of most interest are those that would be tedious to prepare in the home kitchen and require many ingredients. Wheat-based puddings, barbecued bulgur, and Boston-baked bulgur are typical.

Three general areas of our research aimed at this market are canned wheat, frozen products, and instant bulgur. Canned wheat had a preliminary market test 2 years ago in Kansas under the name of Redi-Wheat. The test indicated a good possibility for developing a canned wheat market but also showed some deficiencies to be overcome. Only two products were available for the test. These products needed a considerable amount of kitchen skill and preparation if they were to be served with suitable menu variety.

Recent progress on canned wheat includes extensive formula developments to provide variety in canned products. Preliminary development has begun on flavoring packets of many types that can be singly added to the canned wheat to make entirely new recipes with minimum kitchen effort. In addition, we are making some technical improvements in the canning process.

We have laboratory tested quite a list of products that can be canned using wheat as the basic ingredient. Figure 1 is an example of a canned bulgur product. Many bulgur recipes could also be cooked in processing plants and preserved by freezing. We have tested a number of them as frozen products.

As to canned wheat, we are evaluating the use of a rotating retort that agitates ingredients as products are sterilized. Such agitation makes it possible to add dry ingredients and water, seal the cans under vacuum, and cook the product during sterilization. This is easier than cooking the product first and then filling the cans. Processors can pack a wide variety of products without developing a major kitchen operation for each one.

In addition we are developing an instant bulgur that should have wide use in convenience food products. Bulgur can be puffed so it will readily absorb hot water and reconstitute a cooked bulgur almost instantaneously. The product can be used in a number of soup-to-dessert recipes, some of which are shown on Figure 2. These desserts are made with canned or instant bulgur. The Norwegian pudding with fruit and the large white pineapple Bavarian were frozen and ready to eat when thawed.

The instant bulgur products are fairly adequate but some of them do not reproduce the textural qualities of bulgur that has been cooked in the usual ways. By adjusting temperature, pressure, and humidity during the puffing operation, we are producing instant bulgurs with different rehydration rates and quality characteristics. There remains the selection of optimum processing methods based on careful evaluation of the several product formulations being studied.

The Commercial Market for Protein-Rich Foods

Changes in economic levels bring about conditions that should stimulate a market for protein-rich foods. At the lowest economic levels, people depend mostly on low-cost starchy foods such as rice, millet, cassava, and potatoes. As the economic level increases, wheat consumption tends to replace the starchy foods; and, at a later stage, consumption of both the starchy foods and wheat give way to animal protein and fat in the diet.

There are areas of the world in good economic circumstances that provide commercial import markets even though the consumers have less individual wealth than Americans. In Western Europe and Japan, diets are shifting from potatoes and rice to higher cost products. During the transition to higher

economic levels an opportunity exists for market development of vegetable protein products that resemble meat products, but are less costly.

Wheat protein is in severe competition with other plant proteins for such a market; however, wheat protein has advantages of blandness in flavor and unique flow and elastic properties of the gluten fraction. Such advantages can be exploited in new products.

To date, we have made a number of wheat gluten products in the laboratory that resemble meat in stew and other meat items. We have products that serve as meat extenders in meat loaf and other ground meat recipes. Figure 3 shows the wheat gluten stew, as an example. The "meat" in this stew is really a wheat gluten product.

In addition, we have sponsored contract research on the basic properties of gluten. Findings of this research should guide food product developments by teaching us how gluten's elasticity and other properties can be modified as desired. Much remains to be done to improve wheat protein products and to reduce costs to a truly competitive position. It goes without saying that, if such products are good enough, they should find both export and domestic markets, and include some customers who could afford higher priced sources of protein.

The Concessional Market

A significant market for wheat and wheat products has been developing in recent years under donations and concessional sales subsidized by the United States Government. It includes Public Law 480, welfare relief, and school lunch programs. It exists because there are a vast number of underfed people in the world today and it is a humanitarian gesture to distribute the abundance of our farm products to help them. Concessional sales and donations are also used for market development and as an instrument of our foreign policy. Wheat and flour make up a major part of this market and significant amounts of bulgur have also been shipped; about 500 million pounds so far.

Bulgur has advantages over raw wheat and flour in some of the developing countries where wheat has not existed as a food source. The equipment and training required to convert flour to leavened bread are lacking but bulgur can be cooked as is rice. However, food habits are not easy to change and many rice eaters only reluctantly will use bulgur. A clear white kernel that would more nearly resemble rice would be more easily accepted by these people. Such a product might capture a substantial market if it could be sold at a lower price than rice. It would thereby provide a useful outlet for surplus wheat.

On a small laboratory scale we have now prepared bleached, peeled wheat. Careful milling or chemical removal of the outer bran layers, followed by a bleaching procedure, produces the product shown in Figure 4. The crease is very evident in this magnified picture. Figure 5 shows that the crease

can be cleaned but, to date, at the expense of other qualities. The products shown represent our current progress. We believe we can find better ways for making peeled wheat that will be attractive while preserving nutrients. We expect to reduce processing costs. In addition we plan to reduce cooking requirements because fuel is short in some of the areas where the product might be useful.

Another aspect of our program is recipe and menu development for bulgur. Bulgur has been introduced into welfare food distribution and school lunch programs both at home and abroad and is being eaten by an increasing number of people. If the bulgur is well-prepared these people may be good customers later. This is especially important in the school lunch programs where children from all economic levels may participate and are forming food habits that will stay with them. If an inadequate job is done in preparing bulgur for these initial exposures, these people may never wish to use bulgur again.

Clyde Rasmussen of the Western Regional Research Laboratory had an opportunity to observe some of the bulgur distribution programs in the Orient this year. He found a good imaginative job was being done in some places, especially in the Philippines. In Taiwan and Hong Kong there was some indication that a sentiment of cheapness, poor quality, and charity stigma might become attached to bulgur. Such attitudes must not be allowed to develop.

Market development activities abroad to prevent such mistaken ideas and provide a sound marketing basis for bulgur were described here Monday by Mr. Locke. These activities include development of recipes for specific regions and training of cooks to prepare bulgur dishes. Mrs. Marjorie Heid of our laboratory has developed a number of recipes and is actively working with the Human Nutrition Research Division and others wherever called in order to help inform interested people in the cooking methods and recipe availability for bulgur. She plans to be traveling in Asia soon under Wheat Associates sponsorship to extend her activities and to bring back to the laboratory ideas for further developmental work.

I will mention only briefly two other phases of our research that are concerned with the concessional market. First is a high-protein wheat product that is dispersible in water as a milklike supplement for diets in regions of extreme protein shortage. Yesterday, Dr. Draudt of Purdue discussed his work which is conducted under a contract sponsored by the Western Laboratory. The other phase is some cooperative work we are doing to help develop a bulgur-milk solids-butter oil mixture to be used in Chile and Brazil in the AID school lunch and welfare programs, particularly in the slum areas surrounding Rio de Janeiro. Evaluations are being made of such mixtures and our studies in this area are being expanded.

The Emergency Food Supply

The final specialized market I will discuss is the Emergency Food Supply. Our research on foods for emergency stockpiles began in 1959 in cooperation with the Federal Civil Defense agency. After studying factors involved and the conditions of storage and ultimate use of food stocks for Civil Defense fallout shelters, we formulated, produced, and evaluated the bulgur wheat wafer. Samples are shown in Figure 6.

The wafer meets the following specifications: It is within a nutritional limitation established by the Food and Nutrition Board of the National Academy of Sciences; it is made with low-cost abundant raw materials (80% wheat); it is reasonably acceptable to most people; it is compact; it is stable, and it can be eaten as it exists and can also be served in a number of different ways with minor additions of other foods to provide wide variation in the menu. To make the wafers, puffed bulgur is ground coarsely and mixed with shortening, malt extract solids, and salt. The wafers are then pressed warm from the mixture.

Current plans for emergency stockpiles envision about a billion pounds of food. Most of the food so far purchased under this program is in the form of two types of baked crackers, which are about three times as bulky as the bulgur wafer, and lemon- and cherry-flavored hard sugar candy, which provides an inexpensive, compact calorie source of good stability. A half-million pounds of bulgur wafers were purchased last year in the initial commercial procurement. Larger quantities are expected to enter this program in the future. The wafer is considered the product of choice by the research director of the Office of Civil Defense because it best meets the requirements for stockpiling. (Current activity indicates that another 2 million pounds of bulgur wafers will be procured by the end of this calendar year.)

We hope also to encourage the market for bulgur wheat wafers by finding other uses. The mixtures of surplus foods that I mentioned earlier in connection with the AID donations in Brazil can be made in the form of ready-to-eat pressed wafers. We have prepared small lots of such products for evaluation. Similar mixtures have been made in the form of pellets by a method that would make this product even less expensive.

The pressed wafer, as it now exists, makes a very acceptable snack cracker and conceivably could find a market of interest in this role. For this use, a wide range of flavor adjuncts have been formulated into the product, enhancing its acceptability and providing a useful variation in appeal.

We are still conducting research on modifications of formulation and processing of the bulgur wheat wafer to reduce its cost and increase its stability and we are supporting research, by contract at Oregon State University, on an evaluation of product stability. We now anticipate a 5-year minimum shelf life for bulgur wheat wafers and hope, through research, to extend this stability to a minimum of 10 years.

Summary

To summarize, I have discussed one aspect of wheat utilization research which is a systematic development of products to fill requirements of certain specialized markets at home and abroad that now exist or are believed to be developing. Four specific markets included were: The commercial market for convenience foods; the commercial market for protein-rich foods; the concessional market, including donations and concessional sales subsidized by the U. S. Government; and the emergency food supply. Canned, frozen, and instant dehydrated products are being developed to fit into the growing trend for use of ready-prepared or easy-to-prepare foods. Meatlike products of high-protein content are being developed to provide an intermediate step in the trend away from starchy to high-protein foods. For use in some of the developing areas of the world, bleached, peeled wheat that will resemble rice is being developed to better satisfy rice-eating peoples and an inexpensive milklike beverage, for protein enrichment of diets. New recipes are being developed to improve the variety of use and the acceptability of bulgur wherever it is eaten. Pressed bulgur wheat wafers have been developed for stockpiling in Civil Defense fallout shelters. The concept of a ready-to-eat, pressed bulgur wheat wafer may have further implications in the concessional and convenience markets.

Fig. 1 Canned, Boston baked bulgur.

Fig. 2 Bulgur desserts: apricot supreme, pineapple Bavarian, chocolate parfait, and Vetegrot, a Norwegian pudding with fruit.

Fig. 3 Gluten, meat substitute, prepared in a stew.

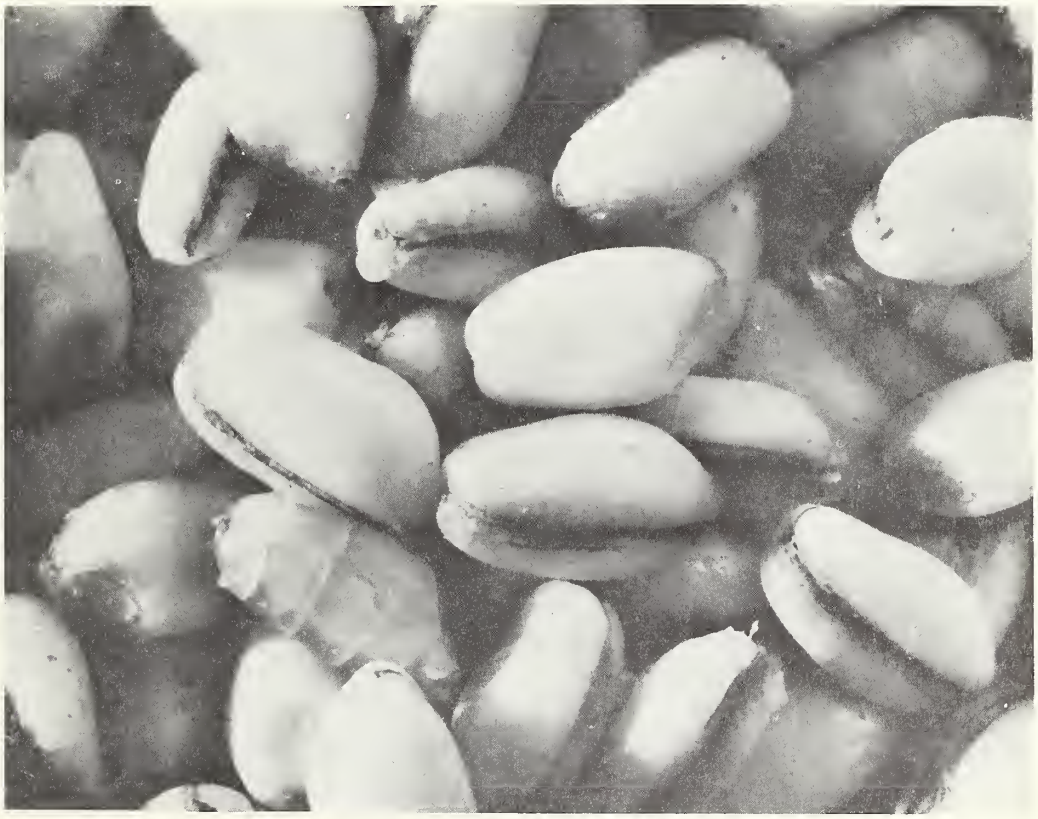


Fig. 4 Peeled wheat; crease strip not removed.

Fig. 5 Peeled wheat; chemically peeled to remove most of the crease stripe.

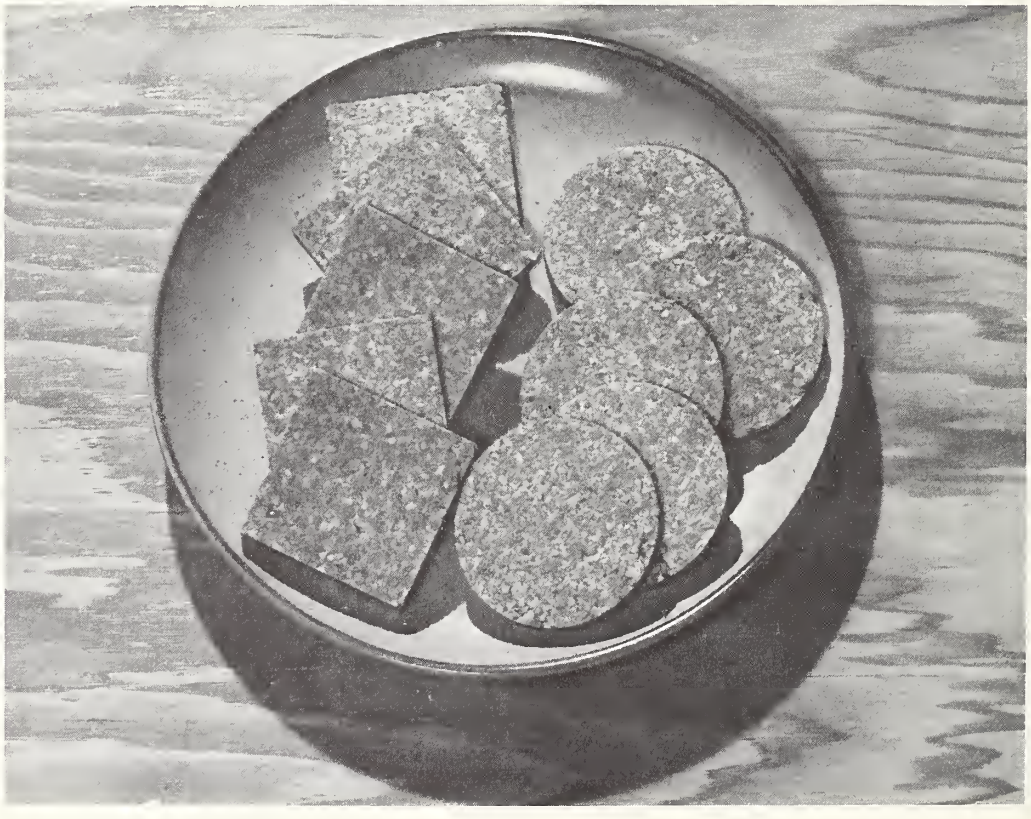


Fig. 6 Bulgur wheat wafers, for civil defense and other uses.

ADVANCES IN WHEAT GLUTEN PROTEIN CHEMISTRY

R. J. Dimler, Chief, Cereal Properties Laboratory
Northern Utilization Research and Development Division,
USDA, Peoria, Illinois

The gluten fraction of wheat sooner or later comes up for consideration in almost any discussion of wheat utilization. The importance of gluten may be viewed from several different standpoints. In bread baking, contributions of gluten to dough mixing and bread properties have been recognized for many years. Potentials for the utilization of gluten for industrial applications and food products have been discussed repeatedly and some advances made in actual practice. In most cases, the characteristic of gluten that stands out is the cohesiveness and elasticity in the hydrated state. Since these properties of the wheat gluten are not only important but essentially unique to wheat, considerable research has been and is being conducted on why gluten has the properties it does. Since gluten is primarily protein, research on the chemical structure and properties of the gluten proteins is providing one avenue toward a better understanding of the gluten fraction of wheat.

I will review some of the more recent advances we have made in our studies of the chemistry of the wheat gluten proteins. Because of the limitations of time, the discussion will be limited to only a few aspects of our work and will not include a discussion of the research on wheat proteins being conducted in an increasing number of other laboratories.

As background, let us first review what gluten is and what its gross properties are. Gluten generally is prepared from flour as indicated in Figure 1. Flour is mixed with water to give a dough in which the hydrated gluten forms a continuous elastic matrix. When this dough is kneaded under water, the starch is washed out, leaving the gluten as a cohesive elastic product shown in Figure 2. Here we see a hydrated mass of gluten being stretched. The gluten has a combination of properties, being both rubbery and somewhat fluid. In dough mixing and bread baking a very critical combination of these properties is required. From the standpoint of other uses for wheat, we believe that this gluten protein, or the flour containing it, can find applications in which advantage is taken either of these properties directly or of the chemical features of the wheat gluten proteins that give them properties different from other proteins. Cereal chemists are seeking to determine why gluten has the characteristics demonstrated in this picture. While they are still far from having the complete answer, progress definitely is being made.

In general, the properties of a substance reflect the properties and structure of the molecules and their effect one on another. Our research, therefore, has been directed toward finding out more about the molecules of protein in the gluten. Separation of gluten into two fractions, as shown in Figure 3, is our first step. At the turn of the century, T. B. Osborne

fractionated gluten on the basis of solubility in aqueous alcohol. Gliadin is the fraction soluble in 70-percent alcohol, while glutenin is the insoluble residue. This difference in solubility is accompanied by differences in other properties.

The fact that gliadin differs from glutenin is demonstrated, as shown in Figure 4, by a comparison of the two fractions when wet with water. Gliadin, in the center picture, is fluid or sirupy. Glutenin, on the right, is cohesive and elastic, but is much stiffer than the original gluten. Looking back at the gluten in the left-hand picture, we realize immediately that it combines the characteristics of the gliadin and glutenin fraction. The gluten has the cohesive and rubbery nature of glutenin moderated by the gliadin to give some fluidity and softness.

This great difference in properties between gliadin and glutenin suggests that there must be important differences between their molecules. Characteristics such as the rubberiness of glutenin also must have a basis in molecular structure and the interactions between molecules. Let us turn our attention, then, to advances that have been made in knowledge and understanding of the protein molecules in wheat gluten and its two fractions, gliadin and glutenin.

Protein molecules are built up through the chemical combination of a number of different amino acids. Some of the representative amino acids found in wheat gluten proteins are shown in Figure 5. Each type contributes in a somewhat different manner to the properties of the molecules and to their effect on each other. Acidic amino acids, represented by glutamic acid, and basic amino acids, represented by lysine, contribute a charge to the molecule. Under certain conditions, only a negative charge or a positive charge is effective. In such cases, since like charges repel each other, the molecules tend to be forced apart and may, for example, go into solution. The amount of these charged groups, either acidic or basic, is quite small in the case of gluten proteins. This helps to account for the rather limited solubility of gluten in water. However, this is not the only factor which is responsible for the water insolubility of the gluten protein.

The most abundant type of group in the wheat gluten protein is the amide group present primarily in the form of the amino-acid glutamine. Because of its ability to form hydrogen bonds it has a marked influence on the solubility and related characteristics of the protein. I will have more to say later about hydrogen bonding and the amide group because this is one of the areas in which we have been conducting research.

The next amino acid, proline, influences the shape of the molecule because it puts a twist or kink in the chain of amino acids that are linked together chemically.

The neutral type of amino acid is exemplified by leucine. In general, this type of amino acid will lower the tendency of the protein to dissolve in water and may increase its tendency to dissolve in various organic solvents such as alcohol. Since there are a number of other neutral amino acids besides

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leucine in the wheat gluten protein, the content of the neutral type is actually quite high.

Crosslinkages through disulfide bonds are provided by the cystine in the gluten protein. This part of the protein structure is very important relative to gluten properties. There is increasing evidence, for example, that in some way cystine and the disulfide bond are related to the mixing characteristics of dough. Support for this belief is given by the long-standing observation that splitting of the disulfide linkage causes loss of the elastic properties of wheat gluten.

From this review of the types of amino acids in gluten proteins, we can anticipate that the properties of the protein will depend on the relative amounts of each type of amino acid present. Some will change the properties in the same direction; others will have opposing effects on the properties. In addition, the total size of the molecule will also influence properties. Our recent studies on the chemistry of wheat gluten proteins has emphasized the cystine group with its disulfide crosslinkage and the glutamine group with its ability to cause hydrogen bonding. Attention also has been given to molecular weight and other molecular properties for which there will not be time to review.

Turning first to the disulfide linkages of cystine, we find an explanation for a considerable part of the difference between gliadin and glutenin. Our present viewpoint on the disulfide bonding is summarized in Figure 6. Admittedly, diagrams of this type may be an oversimplification, but are useful to illustrate the point. Two types of crosslinkage may exist. One type essentially forms loops in the molecule. The line represents a series of amino acids joined through peptide linkages. Each such series is separate and essentially independent in the case of the molecules of gliadin.

In the case of glutenin, however, one series of amino acids or chain is linked to another through the disulfide bond. In this way, a very large molecule can be built up. These larger molecules will be less soluble. Therefore, the high molecular size of the glutenin probably accounts for the insolubility or failure of glutenin to dissolve in alcohol, whereas gliadin does dissolve.

Reduction will break the disulfide bonds yielding SH or sulfhydryl groups. This not only lets the loops open up but also breaks the linkage between individual chains of amino acids. The resulting products then should be rather similar regardless of whether they come from gliadin or glutenin. Of course, we must remember that not all of the chains are identical. Therefore differences in detail may exist.

I thought you might be interested in seeing some of the measurements and observations that bring us to this conclusion concerning the nature and difference of disulfide bonding in gliadin and glutenin. The high molecular weight of glutenin was the first characteristic to become evident to us.

Figure 7 shows the result of applying a technique called starch gel electrophoresis to wheat gluten protein and its two fractions, gliadin and glutenin. In this procedure a slab of starch gel is prepared extending somewhat below the bottom of this figure. A solution of the protein is placed in a slit in the gel; then an electric current is applied by attaching the two ends of the slab to a source of direct current. This causes most of the proteins to move. The distance each kind of protein molecule moves is dependent on the electrical charge it carries. In other words, the relative number of carboxyl groups or amino groups, etc. After the proper length of time, the current is removed and the gel is stained or dyed with a dye that colors the proteins producing a band wherever there is a particular kind of protein molecule.

As we look at the pattern of gluten proteins, we see that there are a large number of bands representing different kinds of proteins that have moved upward in the gel. In addition, there is a dark blue region at the point where the protein was originally placed. For some reason this part of the gluten protein failed to move through the gel. Additional information is obtained by looking at the pattern for gliadin and glutenin. We see that the protein that moved into the gel was gliadin, whereas that which failed to move was the glutenin. We now know that this failure of the glutenin protein to move into the gel was a result of its high molecular size. The starch gel has exceedingly small pores through which the protein must move. The glutenin molecules were too large to penetrate these pores. Actual molecular weight measurements on gliadin and glutenin confirmed this conclusion. Gliadin molecules have a molecular weight generally in the range of 20,000 to 50,000, whereas the glutenin molecules covered a very broad and much higher range extending up into the millions.

Starch gel electrophoresis also gives us an indication of what happens when the disulfide bonds are broken by reduction. In turn, we also get an insight into the difference in the type of bonding in gliadin as compared with glutenin.

Starch gel electrophoresis patterns for gliadin and glutenin before and after cleavage of the disulfide bonds are shown in Figure 8. The first thing to notice is the marked change on reduction of the glutenin. Native glutenin failed to move into the gel. In contrast, reduced glutenin is all able to move and yields a number of bands indicating liberation of a number of different kinds of molecules of protein. This fits perfectly the picture we saw earlier of the glutenin molecule being made up of a number of chains of amino acids, these chains being linked together through disulfide bonds. When the disulfide bonds are broken by reduction, the individual chains are then small enough to move into the gel.

Gliadin shows much less change in starch gel pattern on reductive cleavage of the disulfide bonds. In fact, a close inspection of the patterns shows that the same number of bands are present after reduction as in the native protein pattern. The only change has been a slower movement of all of the bands. This result, together with some additional studies we have made on

separated components, leads us to propose that chains of amino acids are held in loops but have no crosslinkages from one chain to another. Reduction or cleavage of the disulfide bond opens the looped molecules, letting them be more extended. As a result, they do not move as easily through the starch gel. This then accounts for the difference in rate of movement, while at the same time the same number of bands and approximate relative positions are retained.

Finally, we believe that some of the chains of amino acids that are building units in the glutenin are identical or similar to the chains in some of the gliadin molecules. Comparison of a number of starch gel electrophoresis patterns of reduced gliadin and reduced glutenin has shown that for each band in the gliadin pattern there is a corresponding band in the glutenin pattern, although the relative intensities of the bands may differ considerably between the two patterns. However, we have not yet proven that the protein in corresponding bands is identical. Considerably more research will be required before such a conclusion can be definitely reached or discarded.

The formation of open chains on cleavage of the disulfide bonds in both gliadin and glutenin opens interesting possibilities for further chemical modification of the protein with at least some degree of control over molecular size and shape. As shown in Figure 9, the reduced form of the protein with its sulfhydryl or SH groups can be oxidized to again form disulfide linkages. We have found that by controlling the conditions of oxidation, we can take all of the reduced protein to a product that has some resemblance to gliadin while under other conditions the product bears some resemblance to glutenin. I wish to emphasize, however, that we do not claim to have resynthesized either gliadin or glutenin, identical to that which is in wheat gluten. If the reduced protein is oxidized in dilute solution, the molecules are so far apart that it is easier to form a disulfide linkage within one molecule than as a crosslinkage between molecules or between different chains of amino acids. Linkage within the molecule then forms a loop much as we had in the original gliadin. This product is alcohol soluble and has molecular weight and other properties similar to those of the original gliadin.

Oxidation of the reduced material in very high concentration or as a suspension of swollen solid particles results in disulfide linkages bridging from one chain of amino acids to another. The product, when hydrated, shows some elasticity and cohesiveness reminiscent of the glutenin but not as well developed. This property, together with the high molecular weight obtained on the product, indicates that a considerable amount of crosslinkage has occurred between amino acid chains as a result of the closeness of the amino acid chains or molecules to each other in the concentrated solution. When more than two SH groups occur in each chain of amino acids, one would expect eventually to get a highly crosslinked network type of combination in the product. This apparently does happen under some of the conditions we have investigated.

These results on the reactions at the disulfide bond in wheat gluten proteins brings out two important points. One is that through cleavage or breakdown of the disulfide bond, one obtains a more nearly homogenous material

which in itself should be of interest from the standpoint of utilization studies. The other is that disulfide bridges can be reformed in different ways and thereby provide a further range of products and properties.

Let us now turn to our other area of emphasis, namely the glutamine unit in the gluten proteins. Figure 5 recalls for us the chemical structure of the glutamine unit and the large amount present, namely around 42 percent of the total protein. We note here that the glutamine provides a position for hydrogen bonding. The active group in this bonding is the amide group. There has been considerable speculation and disagreement about hydrogen bonding, and particularly about its existence and function in protein molecules. However, we have rather conclusive evidence that hydrogen bonding through amide groups of the glutamine residues does occur in the wheat gluten proteins and that it does contribute significantly to the properties of the gluten proteins.

The general nature of the hydrogen bonding of amide groups is shown in Figure 10. The amide group consists of a carbon carrying a doubly bonded oxygen and a nitrogen, which in turn has two hydrogen atoms attached to it. When two of these amide groups come close enough to each other, one of the hydrogens on each nitrogen is attracted by the oxygen of the other group with the result that for all practical purposes these two hydrogens are shared between the two amide groups. This sharing of hydrogens constitutes hydrogen bonding.

Although a single hydrogen bond is relatively weak, the total bonding force or attractive force can be quite large if a number of amide groups are present. Such a situation is suggested by the diagrams in Figure 11. The three circles represent three molecules of gluten protein. The arrows represent just a few of the many amide groups present on each molecule. You will recall from Figure 5 that these amide groups are part of the chemical structure of the glutamine units in the chains of amino-acid residues that make up the molecules. Since 40 percent or more of the amino-acid residues are glutamine, there obviously will be a considerable abundance of these amide groups. Therefore, when two molecules of the protein come close to each other there will be a number of amide groups on the surface of each that can come close enough together for hydrogen bonding. For a rather simple analogy, we might compare each of these protein molecules to the seed of a rather common weed. The cockleburr probably is familiar to all of you. This burr is covered with a multitude of little hooks. Each of these hooks is analogous to the amide group on the wheat protein molecule. Although any one hook will not hold very tightly, you know that the cockleburrs will stick to each other or to your clothes with considerable tenacity when all the hooks on one side of the burr become entangled with those of another burr or with the threads of your clothes.

We have reached this conclusion concerning the interaction of amide groups because of various studies we have made in which the behavior of the molecules were changed by things that would involve the amide group. Two types of observations are depicted in Figure 12. We have looked at the effect

of different solvents and also at the effect of making chemical changes in the structure of the molecule. Water solutions of urea are noteworthy for their ability to dissolve proteins that are insoluble in water alone. The diagram on the left offers an explanation for this ability of urea to dissolve wheat gluten proteins. The molecule of urea is itself an amide. Therefore, it has an attraction to the amide groups of the protein molecule. For all practical purposes, molecules of urea attach themselves by hydrogen bonding to the amide groups and thereby cover them up. As a result, the protein molecules no longer are hydrogen bonded to each other. This lets them move apart and go into solution.

Another way of decreasing the effectiveness of the amide groups is to change them to ester groups as indicated in the middle of the figure. The methyl ester shown in the lower right-hand corner has almost no ability to form hydrogen bonds. This chemical change is analogous to cutting the little hooks off of the ends on a cockleburr, but leaving the base of the hook intact. As we replace more and more of the amide groups with ester groups, we weaken the overall bonding between two molecules. Therefore, again, we make it easier for the molecules to separate from each other and go into solution.

The type of experimental data which brings out these effects is shown in Figure 13. Here we have a comparison of solubility in water and in urea for both the native gliadin and the protein after approximately half of the amide groups have been replaced with methyl ester groups. A measure of relative solubility is obtained by determining how much salt or sodium chloride is required to precipitate the protein from solution. As we look at the left-hand side of the graph, we see that when water containing just a little acetic acid is the solvent the native gliadin is precipitated before its methyl ester. Therefore, the change from amide to ester groups has increased the solubility. As I mentioned earlier, this is to be expected since we have decreased the number of hydrogen-bonding groups and therefore have made it easier for the molecules to separate from each other and go into solution. On the right-hand side of the graph, we see that the opposite situation occurs in urea solution. At first this may seem contrary to what we have been saying about the effect of methyl ester formation. However, a logical explanation is possible and fits the picture that we have been drawing. First of all, the native gliadin is much more soluble in urea than it was in water. You will notice that along the base line the scale of concentration for the sodium chloride has been changed by a factor of 10 in going from the water to urea solution. The fact that so much more sodium chloride is required to precipitate gliadin from urea demonstrates the much greater solubility in urea. As we saw previously, this can be accounted for by assuming that the molecules of urea attach themselves to the amide groups and thereby protect the protein molecules from attaching themselves to each other and coming out of solution. When we change the amide groups to ester groups, we now have fewer points at which the urea can attach itself and have a solubilizing effect. Other attractive forces between the molecules now come into play, although they are much weaker than amide hydrogen bonding. Since there now is less solubilizing influence by the urea, the methyl ester is precipitated from solution by lower concentrations of sodium chloride. The important point, then, is that the solubility characteristics of gliadin and of its methyl ester in water

and in urea can best be explained on the basis of this attraction between amide groups.

Let us return now to the comparison of the properties of gliadin and glutenin:

GLIADIN	GLUTENIN
Alcohol soluble	Insoluble
Fluid when hydrated	Cohesive, rubbery
Insoluble in water	

These properties represent a combination of the various influences of structure, some of which we have discussed in a fair amount of detail. Glutenin is insoluble in alcohol, while gliadin is soluble. This difference can now be attributed to the very high molecular weight of the glutenin. When we break the disulfide bonds, we get smaller molecules from glutenin--in fact, molecules that are approximately the same size as those in gliadin. We have seen that we can reform the disulfide bonds from these fragments in such a manner as to avoid returning to high molecular weight. When we do so, the product then has a molecular shape and solubility in alcohol similar to that of gliadin. This provides rather conclusive evidence that this difference in solubility between gliadin and glutenin is primarily a result of molecular size and shape.

The difference in properties of the hydrated mass is a result of two factors, both of which are necessary. The cohesive, rubbery characteristic of glutenin is destroyed by breakage of the disulfide bonds. Therefore, the high molecular weight is necessary for the characteristic properties of the glutenin. These properties also are destroyed when part of the amide groups are changed to ester groups. Therefore, we can conclude that the attractive forces between molecules exerted through the hydrogen bonding of amide groups also is a factor in the development of the cohesive, rubbery characteristics on hydration. Obviously, the amide group interaction alone is not sufficient since gliadin has essentially the same complement of amide groups. The abundance of amide groups in both gliadin and glutenin, however, does account in large part for the insolubility of both of these proteins in water.

In summary, progress has been made in the understanding and control of some of the properties of the wheat gluten proteins. Particular attention has been given to two types of bonding; one, a chemical bonding through the disulfide linkage, and the other a weaker bonding (hydrogen bonding) through the amide groups. The work I have reported represents a few more steps along the pathway toward an understanding of wheat gluten and its properties. This pathway, in turn, also leads to increased ability to control and modify the protein properties in order to increase the utility of wheat and products derived from wheat. I am confident that with the increasing research effort that is being devoted by many laboratories to the study of the wheat proteins, we can expect a continuation and acceleration of advances.

Fig. 1

Fig. 2

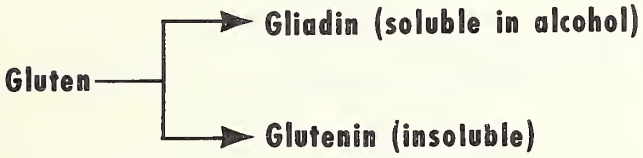


Fig. 3

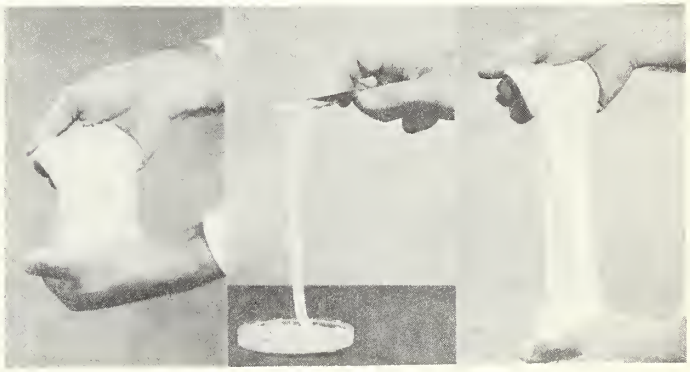
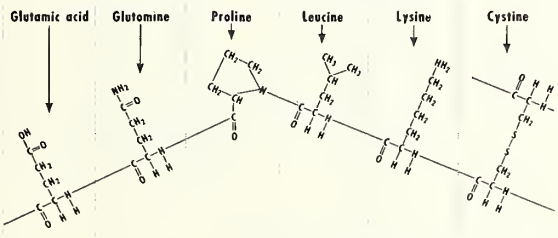


Fig. 4

Representative Amino Acids in Wheat Gluten Protein



Type	Acidic	Amide	Secondary	Neutral	Basic	Sulfur
Content	?-Low	42%	14%	7%	1.2%	2.1%
Significance	Negative charges	Hydrogen banding	Twists peptide chains	Nonpolar	Positive charge	Cross-linkage

Fig. 5

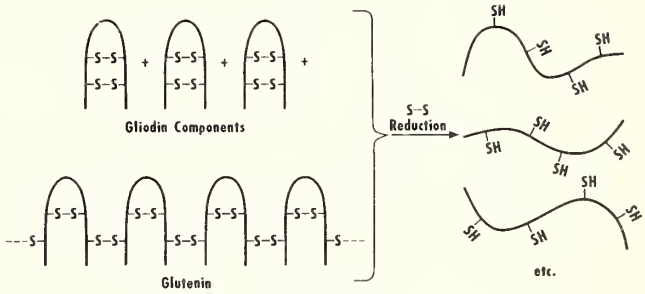
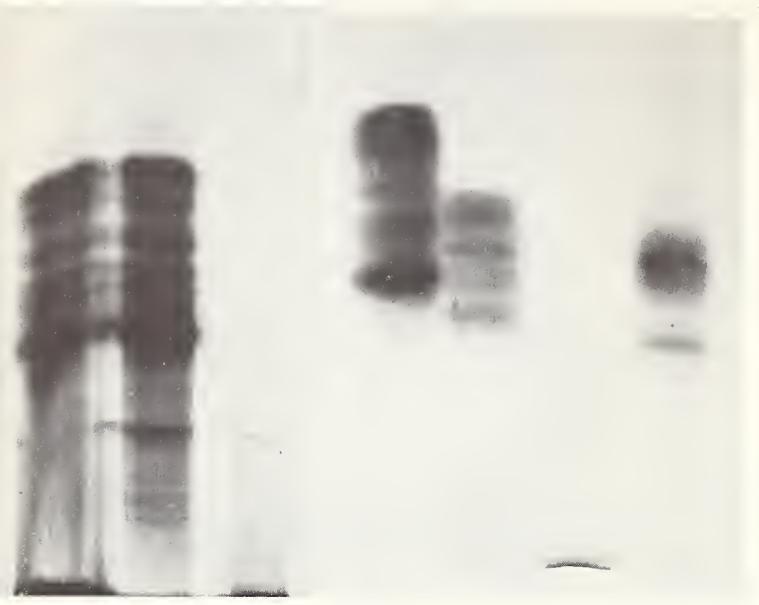


Fig. 6



Gluten Gliadin Glutenin

Fig. 7

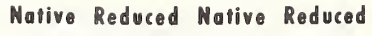


Fig. 8

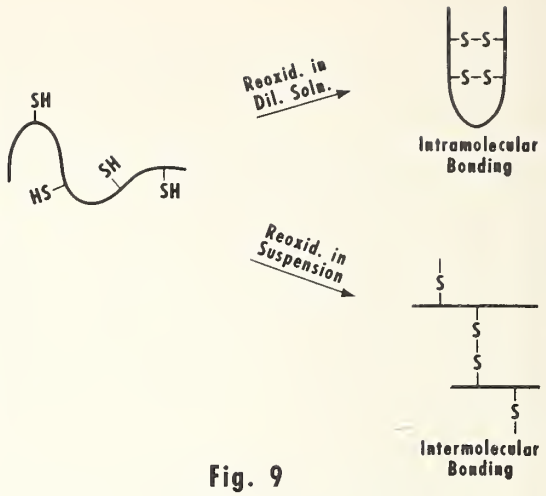
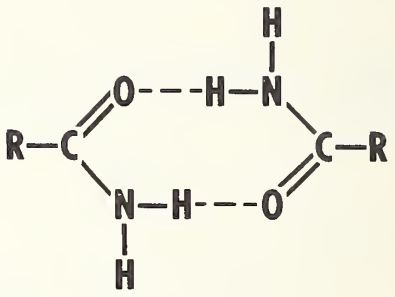


Fig. 9



Hydrogen Bonding of Amide Groups

Fig. 10

Attraction Through Amide Groups

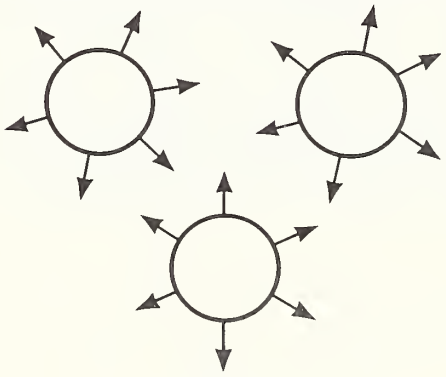
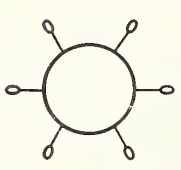
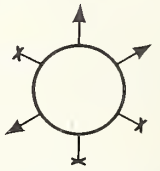


Fig. 11

Solvent and Chemical Structure Influence Interaction of Molecules



Urea (O) in Solution



Change of Amide (→) to Ester Groups (—X)

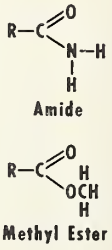


Fig. 12

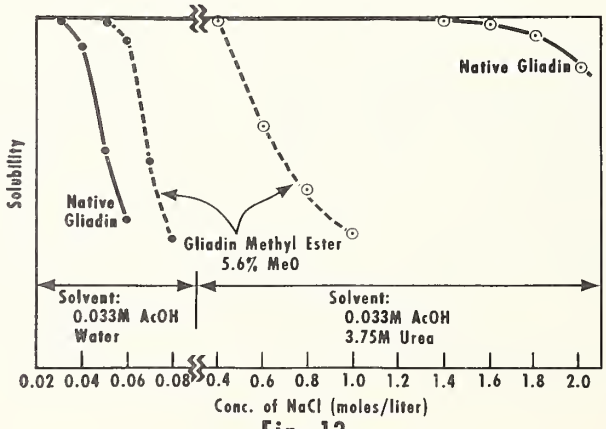


Fig. 13

ENZYME SYSTEMS IMPORTANT IN WHEAT UTILIZATION[1/]

John A. Johnson,[2/] James R. Fleming, and Masayuki Ikemiya
Department of Flour and Feed Milling Industries,
Kansas Agricultural Experiment Station, Manhattan, Kansas

Wheat is a living organism. It is endowed with faculties to respire, to grow, and hence to reproduce and eventually to die. Like for all living organisms, the reactions that give life to wheat are stimulated by organic catalysts, called enzymes. While the enzymes found in wheat are many and varied, only a few have been recognized as significant to industrial utilization either in the production of food or nonfood products.

Enzymes, being catalysts, fulfill the function of altering the speed of reactions. In wheat, they serve the fundamental purpose of creating, through synthesis, stores of food for the future or to facilitate the step-wise breakdown of metabolites necessary for new life. Enzymes serve not only to provide metabolites for the new creation but may serve to eliminate poisons or toxins that would be fatal to life. Thus, the most important role that can be assigned to the enzymes of wheat is to provide and sustain life of the wheat from one generation to the next. Without enzymes there could be no wheat and without wheat or its equivalent there could be no animal or human life.

But man is not satisfied that such efficient catalysts as enzymes should serve only for the purpose of sustaining life and maintaining species. Through research, several of these catalysts have been concentrated, isolated in some instances and their usefulness extended to commercial applications. They alter the speed or reactions *in vitro* as well as *in vivo*. Notable, among the functions of enzymes in industry have been the conversion of carbohydrates and proteins of rye, corn, wheat, and rice in the brewing and distilling industries, the rapid ripening of cheeses, desizing of cloth, modification of starch and protein during bread production, the conversion of starches to syrups and sugars, and the conversion of glucose in eggs to gluconic acid preceding dehydration.

The enzymes of wheat have not served all industrial applications calling for specific catalysts. Indeed, man uses certain microorganisms as a reliable and economic source for many enzymes. The enzymes of wheat which have been most widely applied to industrial processes have been the amylases and proteases. Other enzymes of wheat which have important implications in storage and modification of kernel structure include the lipase, lipoxidase, cytolytic and respiratory enzymes, and glutamic acid decarboxylase.

1/ Cooperative investigations with the U. S. Department of Agriculture, ARS; project supervised by the Northern Utilization Research Laboratories, Peoria, Illinois.
2/ Presented by Dr. Johnson at the Second National Conference on Wheat Utilization Research, Peoria, Illinois, October 28, 1963.

Glutamic Acid Decarboxylase. Keeping wheat viable and safe during storage has always been a serious problem. Certain enzymatic processes involving respiration, chemical deterioration and loss of viability can take place in resting seed at relatively low moisture levels. Normally, many of these changes are associated with metabolic activities of saprophytic fungi although other biochemical changes in the seed also occur.

Recent work of Linko and Milner has pointed to the importance of glutamic acid decarboxylase. Raising the moisture level of grain from 16 percent to 18 percent causes a sudden evolution of carbon dioxide and a decrease in both alpha-keto glutamate and glutamic acid. It is pertinent that these changes in stored grain take place at moisture levels lower than the 30 percent required for germination. The loss of the tricarboxylic and glutamic acids apparently are the first signs of changes that take place when wheat is wetted. These reactions contribute to subsequent deteriorative changes as wheat is stored at slightly elevated moisture levels.

The Amylase. Of all the enzymes associated with cereals, alpha- and beta-amylase have received the most attention. They are used for conversion of insoluble starches to soluble sugars in the brewing and distilling, baking, textile, laundry, and sugar industries.

Beta-amylase is normally abundantly available in sound cereals and it is responsible for the production of maltose from available starch. Alpha-amylase activity is normally low in sound grain but may be activated by germination. Alpha-amylase serves as a dextrinizing catalyst to modify available starch. Numerous sources including enzymes of sprouted cereals, fungal and bacterial origin are used. Each source has special properties which lends it to commercial utility.

The functions of amylase enzyme supplementation in breadmaking are well known. During fermentation, the starch damaged through milling is available to alpha- and beta-amylase which work together to produce fermentable sugar. Late in the baking process, as starch is gelatinized, alpha-amylase modifies the starch by production of dextrins. This causes a softer bread crumb with improved anti-staling properties. Fungal, as well as cereal alpha-amylase is used for this purpose.

The Proteases. The catalysts that accelerate the hydrolysis of protein are of particular significance in several areas of utilization. They are involved in wheat storage, wheat modification through malting and in bread baking. Unfortunately, our knowledge concerning the proteases is scanty. The proteases represent a series of enzymes, each with rather high specificity. Usually protease activity is measured using foreign or auxiliary substrates. Seldom is knowledge available to indicate the specific linkages hydrolyzed. In malted wheat there are exo- and endo-peptidases whose activity is dependent on specific amino acid residues found in the protein chain. There are those enzymes that split peptide bonds between glycyl l-tyrosine for example, and many other combinations. Interest in these facts today are academic but such knowledge could have impact on the technology of wheat utilization of the future.

The role of the proteases in modifying the structure of the kernel during malting is appreciated. These catalysts cause the protein of wheat and barley to be solubilized. Some of the proteins are hydrolyzed to the state of free amino acids but seldom is the protein completely hydrolyzed. Rather, small polypeptide chains are created depending on the extent of proteolytic action. The proteins of wheat, rice, or barley, partially hydrolyzed as they are, provide beer with a stable-foaming characteristic. The proteins also contribute to the problem of "beer chill haze" if they are not sufficiently modified.

The use of proteases in commercial baking has gained some importance since 1951 when fungal enzyme concentrates with potent proteolytic activity became available. Proteases used in breadmaking, hydrolyzing numerous linkages of the protein molecule, reduces the dough mixing requirements and increases the dough extensibility. Their use permits the baker to develop a dough that will machine without tearing and one that has pan-flow. The bread from such dough will be more uniform and the crust color, a richer brown.

The Cytases. During malting of grain, not only do the amylases and proteases cause extensive modification of starch and protein but another series of catalysts known as the cytases play an important role. These enzymes modify the cell walls and hydrolyze the beta-glucan-araboxylan-protein complex in which are embedded the starch granules. Among the cytolytic enzymes of direct importance to modification during malting are the endo- and exo-beta-glucanases and pentosanases which hydrolyze the hemicellulose. This action permits the entrance of amylases and proteases which hydrolyze the starch and proteins, respectively. The value of cytolytic activity in grain used for mashing during brewing has been recognized but whether these enzymes play an important role in conditioning of wheat for dry flour milling is unknown. It may be that these enzymes are responsible for changes occurring in wheat as it is held in the temper bin. Presumably, they are not without their influence in wheat exhibiting incipient germination.

Lipase. Interest in lipase from the viewpoint of wheat utilization resides in the fact that it is responsible for release of fatty acids in cereals during storage. For many years, the development of free fatty acids in grain has been used as a criterion of wheat condition. Apparently, as the moisture is increased to levels beyond 16-17 percent, the lipase can hydrolyze fats to glycerol and free fatty acids. The presence of free fatty acids by themselves does not appear to be detrimental to quality of wheat for processing. Rather, the presence of free fatty acids is indicative of other more serious changes that may have taken place.

The occurrence of high lipolytic activity in certain cereals such as oats, creates serious problems. In this case, the lipolytic activity coupled with a lipoxidase causes the development of objectionable odors and tastes in stored rolled oats. This is frequently overcome by heat treatment to inactivate the lipase.

Lipoxidase. As distinguished from lipase, lipoxidase catalyzes the oxidation of fats. It accelerates the development of rancidity in fat and

the oxidation of pigments in durum wheat used for macaroni manufacture. Lipoxidase has found acceptance in the baking industry as an oxidant of xanthophyll and carotenoid pigments in flour. A soybean lipoxidase is used extensively for this purpose.

Recent Advances in Cereal Malting. Man has malted wheat or barley for centuries because through this process he could have a relatively rich source of organic, natural catalysts that served a useful purpose in processing technology. It has been generally believed that moisture level approaching 30 percent or more is required to reawaken the metabolism of the resting seed. Recent research has shown that several enzyme systems are activated at considerably lower levels. Notably, the respiration enzymes, glutamic decarboxylase and the cytase systems are activated at moisture levels as low as 16 percent. It was also formerly believed that the embryo was the main site of enzyme development upon germination and that they were translocated from the embryo through the epithelial cells of the scutellum to the endosperm. Germination and growth were necessary corollaries to the development of enzymes. This concept has been seriously challenged recently by cereal researchers in Japan, Australia, England, United States, and Canada.

Numerous workers have reported that gibberellic acid increases as well as hastens the development of amylase, protease and cytolytic enzymes during malting. Yomo in Japan and Paleg in Australia have shown unequivocally that barley from which the embryo was removed would develop large quantities of alpha-amylase in the endosperm if treated with a solution of gibberellic acid. They found that the alpha-amylase activity was increased as much as 30 to 80 times in the endosperm by steeping with gibberellic acid compared to water. This has been confirmed in wheat malting for amylase and protease enzymes by Fleming and Johnson.

A number of experiments demonstrate the effect of certain chemicals on enzyme development without concomitant growth. The data in Table 1 illustrate the effect of gibberellic acid and hydrogen peroxide on alpha-amylase development in malted wheat in which growth was curtailed by not maintaining a high moisture level following the malting process. If the moisture level was below 30 percent, alpha-amylase development was not affected by the presence of gibberellic acid. However, if the moisture level was above 30 percent, gibberellic acid caused the alpha-amylase activity to increase to 48.5 SKB units per gram. The addition of hydrogen peroxide increased the activity to 60.7 SKB units per gram. In none of these treatments was there evidence of root and shoot growth.

In another experiment, the wheat was steeped for 50 days in a 0.1 percent solution of roccal, followed by a steeping in water, gibberellic acid and hydrogen peroxide for 20 hours and then incubated for 2 and 4 days to develop the alpha-amylase. The data are presented in Table 2. As in the above experiment the wheat did not grow but yet when treated with gibberellic acid or a combination of gibberellic acid and hydrogen peroxide, the alpha-amylase was greatly activated. These studies confirm that growth of root and shoot from the embryo are not required for release of alpha-amylase.

Table 1.--Effect of gibberellic acid and hydrogen peroxide on alpha-amylase development in wheat during curtailed growth

Steep treatment	Steep moisture	Alpha-amylase[1]
	%	SKB units/g.
0.001% Gibberellic acid	25	0.0
Water	33	21.3
0.001% Gibberellic acid	33	48.5
0.001% Gibberellic acid + 0.05% hydrogen peroxide	33	60.7

[1] Three-day incubation following steeping.

Table 2.--Effect of gibberellic acid and hydrogen peroxide on alpha-amylase development in nonviable wheat[1]

Steep treatment[2]	Days of incubation 2	Days of incubation 4
	SKB units/g.	
Water	0	0
0.001% gibberellic acid	32.0	43.1
0.001% gibberellic acid + 0.1% hydrogen peroxide	80.2	73.8

[1] Wheat steeped for 50 days in 0.1% roccal solution to prevent germination.
[2] Wheat steeped for 20 hours at 20° C.

Still in another experiment, when wheat was steeped in water for several days and then frozen, the seeds were found nonviable. When such frozen wheat was steeped in gibberellic acid or a combination of gibberellic acid and hydrogen peroxide, the alpha-amylase activity was as great or greater than if the wheat had sprouted in a normal manner. These data are presented in Table 3. It is apparent that oxygen is in some manner related to the development of alpha-amylase.

If aerobic oxidation in addition to gibberellic acid is involved in the development of alpha-amylase, then it should be possible to devise an aerobic system of steeping during cereal malting. The tumbling or rolling of the grain during steeping has been used for this purpose. The effect of "roll steeping" on alpha-amylase development during wheat malting is shown by the data in Table 4. If wheat is steeped in water for 24 or 48 hours, there is no measurable alpha-amylase activity. To develop this activity, the wheat must be incubated. If gibberellic acid is added, the development of alpha-amylase is insignificant unless aerobic conditions accompany the steep procedure. If the wheat is rolled in the air as it is steeped, the alpha-amylase activity is greatly stimulated, even without incubation and subsequent growth of the acrospire and roots.

Table 3.--Development of alpha-amylase in steeped wheat frozen to inhibit sprouting[1/]

Steep treatment[2/]	Alpha-amylase after 3 days incubation
	SKB units/g.
Water	3.0
0.001% Gibberellic acid	67.5
0.001% Gibberellic acid + 0.1% hydrogen peroxide	96.0

1/ Wheat was steeped to 40% moisture and then frozen at -12° C. for 24 hours.
2/ Wheat steeped 24 hours at 20° C.

Table 4.--Effect of aerobic "roll steeping" on alpha-amylase development during malting of wheat

Steep	Treatment hours	Normal steep SKB units/g.	Roll steep SKB units/g.
Water	24[1/]	0.0	0.0
	48[1/]	0.0	0.0
	24[2/]	4.8	8.4
0.001% Gibberellic acid	24[1/]	0.0	12.0
	48[1/]	1.8	80.4
	24[2/]	19.8	43.2

1/ No incubation period following steep.
2/ One-day incubation period following steep.

Whether alpha-amylase and protease are released from precursors or are synthesized has been a point of conjecture. The predominant evidence suggests that these enzymes are synthesized from existing protein during malting. The effect of a number of protein synthetase inhibitors and other chemicals on alpha-amylase development in viable wheat seed is shown by the data in Table 5. It is evident that chlorophenicol and puromycin were most effective. These compounds when added to alpha-amylase did not cause inhibition of activity but did appear to inhibit their development.

One of the problems associated with the use of gibberellic acid in cereal malting is that it causes greater malting losses. Certain other chemicals can be added during malting that appear to be synergistic to the effects of gibberellic acid. Compounds such as indoleacetic acid and maleic hydrazide and potassium bromate may increase both the alpha-amylase and protease activity of malted wheat by 40 to 50 percent without decreasing malting losses.

Another interesting aspect of malting associated with the use of gibberellic acid is the activation of the endo- and exo-glucanases and pentosanases. MacLeod, Miller, and Briggs working in England have

Table 5.--Effect of protein synthetase inhibitors on development of alpha-amylase in sprouted wheat

Treatment	Alpha-amylase
	SKB units/g.
Control[1/]	69
Chloramphenicol 3×10^{-3} m	8
Puromycin, 5 mg./ml.	11
2,4-Dinitrophenol, 2×10^{-4} m	15
p-Fluorophenylalanine, 1×10^{-3} m	14
8-Azo-guanine, 1×10^{-3} m	53
8-Azo-uracil, 1×10^{-3} m	46

[1/] Wheat steeped in water to 40% moisture and incubated for 4 days at 20° C.

demonstrated in barley from which the embryo was removed that gibberellic acid was required to stimulate the breakdown of the hemicelluloses. Seeds from which both the embryo and the aleurone cells were removed showed no glucanase and pentosanase activity suggesting that their release was triggered by gibberellic acid from the aleurone cells.

The concept of enzyme development in germinating cereals today suggests that they are synthesized not as a specific function on the embryonic tissue but rather that an endogenous hormone(s) from the embryo triggers the release of cytolytic, amylolytic and proteolytic enzymes through the aleurone cells. Added gibberellic acid appears to achieve essentially the same purpose as the endogenous hormone(s). The practical significance of these discoveries is that wheat can be caused to develop enzymes without concomitant growth and malting loss. The development of enzymes can be achieved in relatively short periods of time. It is not known whether wheat is modified by enzymes during tempering but it would appear likely that the cytolytic enzymes may play an important role. Further research is needed.

SUMMARY

The most important attribute of enzymes in wheat technology is that the enzymes provide the mechanism for sustaining the life of wheat. However, in commercial utilization of wheat the enzymes play an increasingly important role. They serve to modify wheat that may be used in malting and brewing. They may be responsible for modification of wheat during tempering. They are used extensively to modify starches in production of syrups and sugars, to modify both starch and protein during breadmaking and in several other

processes. During storage of grain, enzymes must be kept at a low level of activity. To have them activated, sets a series of biochemical changes in progress.

Recent research has greatly modified the understanding of how enzymes are released during malting. It is now apparent, that the embryo releases a hormone which triggers the release of amylolytic, proteolytic and cytolytic emzymes from the aleurone cells. Addition of gibberellic acid serves a similar function and thus the need for an embryo is not required for development of enzymes during wheat malting. These concepts may greatly modify industrial processing methods.

POTENTIAL DIETARY USES OF MILL FRACTIONS AS INDICATED BY COMPOSITION

Frank N. Hepburn, Research Biochemist
American Institute of Baking, Chicago, Illinois

Concern over providing better nutrition for the underfed peoples of the world, heightened by the anticipation of increased demands for food which shall result from the population explosion has stimulated a search for new areas of food production and especially those which will provide high quality protein. Recent efforts to utilize the protein of microbiological material, seafoods, and concentrates of leaves and grass are examples. Numerous investigations have also been carried out to find means of improving the utilization of existing food supplies through the feeding of combinations of proteins or supplementation with amino acids. There seems to have been little activity, however, in exploring the possibility of wider use of the by-products of commercial milling; materials close at hand which, by their amino acid composition, offer great promise as sources of high quality protein. The purpose of this presentation is to present the analytical data which suggest that these products should be investigated and evaluated for such use.

The plea for nutritional research in cereals is not a new one. Dr. Hopkins, in reviewing the progress of physiological chemistry for 1917, was quoted by Osborne and Mendel (1) as saying:

> "The present shortage in the food supply of the world makes important every detail of knowledge concerning human nutrition. Even facts which may seem academic need scrutiny, in case at some point or other they may find application in the direction of guidance for economy. . . . Particularly desirable just now is any scrap of knowledge concerning the cereals. Except in arctic climates, bread and cereals are always important items in the food of mankind, and except where wealth has accumulated and luxury come in its train, they are by far the most important."

The early feeding tests of Osborne and Mendel demonstrated the superiority of whole wheat to endosperm and of bran and embryo proteins to that of whole wheat. The practicality of their experimental findings was borne out in practice in the feeding of animals even though the analytical data to explain these differences were not made available for many years later.

In considering the problem of flour refinement for human consumption, these same authors concluded that little could be gained in this country by including bran and embryo in the flour, but that the best use of wheat was in milling flour to contain the greatest possible amount of endosperm as food for man, while feeding the by-products of milling to animals, and thus providing sufficient animal protein to supplement the diet. As we are all aware,

this has proven to be the pattern of choice in this country. Most of us would prefer to continue eating the wheat kernel inside-out, as it were, with the endosperm in the form of white bread enclosing the offals of milling in the form of a delicious piece of meat. But perhaps it is our satisfaction with this arrangement that has delayed investigation of other uses of milling by-products.

In 1945 Hove, Carpenter, and Harrel (2) demonstrated that the protein efficiency of certain mill fractions was unusually high and compared favorably to soybean meal and nonfat dry milk solids. When fed at the rate of 10 percent protein in the diet to young, growing rats, values found were: germ, 2.87; shorts, 2.45; bran, 2.15; red dog, 2.06; nonfat dry milk, 2.84; and soybean meal, 2.14. These authors concluded:

> "In periods of shortages of good quality animal proteins for both man and animals, such data should be useful in planning a better and more efficient utilization of the plant substances which show good protein quality."

There has since been made available data on the amino acid composition of the parts of the wheat kernel and on the products of milling which explain the observations of Hove et al. and permit further speculation as to the value of these materials as protein foods.

Table 1 (3) shows the distribution of selected amino acids in the flours and red dog produced by commercial milling. The greatest differences are seen between the red dog and the three flours. Of greatest nutritional importance is, of course, the difference in lysine content, the limiting amino acid of wheat protein. The data in the first two columns illustrate that the degree of refinement of flour is relatively unimportant in altering the ratios of amino acids. The greatest fractionation occurs with the initial separation of flour.

In Table 2 (3) are given the proportions of the same amino acids in the remaining major mill products together with the values for the whole wheat. As with red dog, lysine and threonine are considerably greater in shorts, bran, and germ than in whole wheat or flour. The reduction in leucine and phenylalanine does not lower these amino acids below their relative requirement. A comparison of these values with nutritional requirements indicates that the pattern exhibited by red dog, shorts, bran, and germ is very nearly that required for adult man. In addition to the better balance of the essential amino acids in these products it should be noted that there is also a more favorable balance of essential to nonessential amino acids, primarily the result of much lower concentrations of glutamic acid and proline.

The high content of water soluble vitamins is an additional benefit of the use of these products as foods. Tables 3 and 4 (4) show the distribution of vitamins in wheat, bran, shorts, red dog, germ, and flours. From the data it can be seen that the bran, shorts, and red dog contain most of the vitamins of the whole wheat, for although the germ fraction is high in certain

Table 1.--Concentration of amino acids in mill products[1/]

/gm. per 16 gm. nitrogen/

	Patent flour	First-clear flour	Low-grade flour	Red dog
Arginine	3.73	3.87	4.68	6.84
Histidine	1.92	2.06	2.14	2.22
Isoleucine	3.91	4.02	3.72	3.42
Leucine	6.63	6.59	6.33	5.77
Lysine	1.97	1.94	2.54	4.13
Methionine	1.73	1.71	1.67	1.70
Cystine	1.76	1.85	1.67	1.40
Phenylalanine	4.77	5.04	4.64	3.55
Tyrosine	3.27	3.35	3.20	2.85
Threonine	2.64	2.73	2.76	3.11
Tryptophan	0.92	1.01	1.01	1.25
Valine	4.32	4.44	4.45	4.91

1/Hepburn, F. N., Calhoun, W. K., and Bradley, W. B. The distribution of the amino acids of wheat in commercial mill products. Cereal Chem. 37: 749-755 (1960).

Table 2.--Concentration of amino acids in mill products[1/]

/gm. per 16 gm. nitrogen/

	Shorts	Bran	Germ	Whole wheat
Arginine	6.85	6.60	6.88	4.71
Histidine	2.20	2.22	2.26	2.12
Isoleucine	3.31	3.29	3.48	3.78
Leucine	5.64	5.51	5.75	6.52
Lysine	4.18	3.77	5.28	2.67
Methionine	1.62	1.48	1.91	1.74
Cystine	1.44	1.45	1.19	1.66
Phenylalanine	3.44	3.58	3.38	4.43
Tyrosine	2.85	2.82	2.84	3.25
Threonine	3.03	2.86	3.42	2.76
Tryptophan	1.29	1.58	0.98	1.13
Valine	4.84	4.69	4.90	4.69

1/Hepburn, F. N., Calhoun, W. K., and Bradley, W. B. The distribution of the amino acids of wheat in commercial mill products. Cereal Chem. 37: 749-755 (1960).

vitamins, the proportion of germ is much less, amounting to only 1-2 percent of the wheat.

Table 3.--Vitamin content of mill products[2/]

/mg./100 gm. 14% moisture basis/

	Wheat	Bran	Shorts	Red dog
Thiamine	.393	.629	1.34	2.80
Riboflavin	.107	.334	.347	.322
Niacin	5.45	26.6	16.0	8.01
Pantothenic acid	1.09	3.91	2.66	1.82
Folic acid	.050	.088	.135	.120
Biotin	.0114	.0440	.0350	.0250
p-Aminobenzoic acid	.383	1.48	1.26	.781
Choline	163.	154.	176.	174.
Inositol	315.	1340.	1080.	808.

2/ Calhoun, W. K., Hepburn, F. N., and Bradley, W. B. The distribution of the vitamins of wheat in commercial mill products. Cereal Chem. 37: 755-761 (1960).

Table 4.--Vitamin content of mill products[2/]

/mg./100 gm. 14% moisture basis/

	Germ	Low grade flour	First clear flour	Patent flour
Thiamine	1.35	1.08	.245	.076
Riboflavin	.487	.124	.048	.032
Niacin	4.53	3.86	2.09	1.01
Pantothenic acid	1.04	.915	.675	.483
Folic acid	.205	.042	.018	.011
Biotin	.0174	.0108	.0042	.0014
p-Aminobenzoic acid	.370	.295	.126	.033
Choline	265.	148.	151.	161.
Inositol	852.	341.	113.	.33

2/ Calhoun, W. K., Hepburn, F. N., and Bradley, W. B. The distribution of the vitamins of wheat in commercial mill products. Cereal Chem. 37: 755-761 (1960).

The distribution of amino acids and vitamins within the mill fractions reflects the degree of separation and concentration of the structural parts of the wheat kernel. The detailed analyses of the Research Association of British Flour-Millers on dissected portions of wheat grain, summarized by Moran (5), show that the highest concentration of vitamins and of soluble proteins was found in the aleurone layer, embryo and scutellum. Because the vitamins are in different proportions within these parts, their amounts will reflect the distribution among the mill products and will vary to some extent according to the particular division of a given mill

operation. Such variation would not be expected with amino acids, however, because the composition of the soluble proteins characteristic of these portions of the wheat tends to be more constant. Thus it would not appear that the amino acid composition of red dog, shorts, bran, or germ would be greatly influenced by altering the proportion of these products in milling, provided that the endosperm proteins of flour are removed to the greatest possible extent in every case.

This fact may prove to be of great importance because of the necessity to reduce the fiber content of shorts and bran. One solution might be to divert a greater percentage of the fiber from the shorts to the bran fraction, thus freeing the former for human consumption leaving the latter for animal feeding. Although red dog and germ may be sufficiently low in fiber, its effect should be ascertained. It has been shown that the effect of bulk must be taken into account when feeding whole wheat to experimental animals. Table 5 (6), presents the results of three methods of calculating the availability of lysine to rats. It can be seen that the total weight gain of rats fed whole wheat yields an erroneously high value for availability due to the weight of the contents of the gastro-intestinal tract on this diet. Such an effect would have to be guarded against in feeding studies with mill products.

Table 5.--Availability values for lysine in wheat, flour, bread, and gluten[1/]

[In percent[2/]]

Performance index[3/]	Wheat	Flour	Bread	Gluten
Weight gain	87	85	84	83
Empty weight gain	74	83	83	83
Carcass nitrogen gain	78	80	83	80

1/ Calhoun, W. K., Hepburn, F. N., and Bradley, W. B. The availability of lysine in wheat, flour, bread, and gluten. J. Nutr. 70: 337-347 (1960).

2/ Percent availability = $\frac{\text{lysine found by rat assay}}{\text{lysine found by microbiological assay}} \times 100$

3/ Method of calculation: gain versus grams available lysine consumed.

Additional information is needed regarding the preparation of these products as food; whether they can be converted to forms readily accepted by those who would benefit from their consumption. Such studies should be accompanied by nutritional research for determining optimal utilization. Although much work is needed, the potential gains to the malnourished and to the milling industry are great.

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LIST OF ATTENDANCE

Ackels, A. A.	Bay State Milling Company	Winona, Minn.
Allen, Wayne B.	Nebraska Wheat Growers & Commission	McCook, Nebr.
Anderson, Herman	Quaker Oats Company	Barrington, Ill.
Anderson, R. A.	Northern Regional Laboratory	Peoria, Ill.
Ashton, Edgar	Nebraska Wheat Commission	Lincoln, Nebr.
Barmore, Mark A.	Western Wheat Quality Laboratory	Pullman, Wash.
Bass, E. J.	International Milling Co.	Minneapolis, Minn.
Bayne, Glen L.	National Assn. of Wheat Growers	Prosser, Wash.
Bechtel, W. G.	American Institute of Baking	Chicago, Ill.
Beckwith, A. C.	Northern Regional Laboratory	Peoria, Ill.
Bitting, H. Wayne	Agricultural Research Service	Washington, D.C.
Borkichert, Melvin	South Dakota Wheat Commission	Pierre, S. Dak.
Brekke, O. L.	Northern Regional Laboratory	Peoria, Ill.
Briggle, L. W.	Agricultural Research Service	Beltsville, Md.
Brownell, L. E.	University of Michigan	Ann Arbor, Mich.
Buchanan, R. A.	Northern Regional Laboratory	Peoria, Ill.
Burbridge, L. H.	Northern Regional Laboratory	Peoria, Ill.
Cantor, S. M.	S. M. Cantor Associates	Ardmore, Pa.
Cantwell, Acord	Indiana Farm Bureau, Inc.	Indianapolis, Ind.
Carp, Alan	Purdue University	Lafayette, Ind.
Carp, Mrs. Alan	Purdue University	Lafayette, Ind.
Chaddock, R. E.	Hercules Powder Company	Wilmington, Del.
Cluskey, J. E.	Northern Regional Laboratory	Peoria, Ill.
Conway, H. F.	Northern Regional Laboratory	Peoria, Ill.
Cotton, R. H.	Continental Baking Company	Rye, N.Y.
Covey, E. A.	South Dakota Wheat Commission	Hamill, S. Dak.
Crowley, Paul R.	General Mills, Inc.	Minneapolis, Minn.
Curtis, Byrd C.	Colorado State University	Ft. Collins, Colo.
Daum, E. N.	South Dakota Wheat Producers	Murdo, S. Dak.
Deobald, H. J.	Southern Regional Laboratory	New Orleans, La.
Deshpande, S. N.	Purdue University	Lafayette, Ind.
Dimler, R. J.	Northern Regional Laboratory	Peoria, Ill.
Doane, W. M.	Northern Regional Laboratory	Peoria, Ill.
Draudt, H. N.	Purdue University	Lafayette, Ind.
DuBois, Don	Hercules Powder Company	Harbor Beach, Mich.
Dunden, W. J.	Midwest Research Institute	Kansas City, Mo.
Durham, Roy K.	Great Plains Wheat, Inc.	Garden City, Kans.
Eastin, Jerry D.	University of Nebraska	Lincoln, Nebr.
Eber, D. S.	Assn. of Operative Millers	Kansas City, Mo.
Edwards, G. H.	Research Assn. of British Flour-Millers	London, England
Enix, James R.	Federal Extension Service	Stillwater, Okla.
Enoch, Duard W.	Interstate Bakeries Corporation	Kansas City, Mo.
Erlander, S. R.	Northern Regional Laboratory	Peoria, Ill.
Erstad, Johannes	Scandinavian Wheat Team (Vaksdal Flour Mills)	Vaksdal, Norway

Fanta, G. F.	Northern Regional Laboratory	Peoria, Ill.
Farnsworth, Helen C.	Stanford University	Stanford, Calif.
Faught, W. A.	Economic Research Service	Washington, D.C.
Finney, Karl F.	Hard Winter Wheat Quality Laboratory	Manhattan, Kans.
Fisher, Forest L.	Colorado Wheat Administrative Committee	Denver, Colo.
Folken, Herbert G.	Agricultural Research Service	Washington, D.C.
Friedman, M.	Northern Regional Laboratory	Peoria, Ill.
Gastineau, J. E.	Northern Regional Laboratory	Peoria, Ill.
Gehrig, E. J.	American Miller and Processor	Chicago, Ill.
Gentry, Wayne B.	Washington Wheat Commission	Spokane, Wash.
Giertz, John W.	The Kansas Milling Company	Wichita, Kans.
Glass, Robert L.	University of Minnesota	St. Paul, Minn.
Golumbic, Calvin	Agricultural Marketing Service	Hyattsville, Md.
Goodman, A. H.	DCA Industries	New York, N.Y.
Graves, R. D.	Northern Regional Laboratory	Peoria, Ill.
Greenberg, Sheldon L.	The Pillsbury Company	Minneapolis, Minn.
Griffin, E. L., Jr.	Northern Regional Laboratory	Peoria, Ill.
Gugliemelli, L. A.	Northern Regional Laboratory	Peoria, Ill.
Haley, William L.	Fisher Flouring Mills Co.	Seattle, Wash.
Hamerstrand, G. E.	Northern Regional Laboratory	Peoria, Ill.
Henderson, L. S.	Agricultural Marketing Service	Hyattsville, Md.
Hepburn, F. N.	American Institute of Baking	Chicago, Ill.
Hesseltine, C. W.	Northern Regional Laboratory	Peoria, Ill.
Hofreiter, B. T.	Northern Regional Laboratory	Peoria, Ill.
Hoover, S. R.	Agricultural Research Service	Washington, D.C.
Horan, F. E.	A-D-M Research Center	Minneapolis, Minn.
Howe, Don	Idaho Wheat Commission	Bonners Ferry, Idaho
Hower, R. K.	National Biscuit Company	Fairlawn, N.J.
Hubbard, J. E.	Northern Regional Laboratory	Peoria, Ill.
Hudelson, P. V.	Daily Pantagraph	Bloomington, Ill.
Huebner, F. R.	Northern Regional Laboratory	Peoria, Ill.
Huffman, Robert	North Dakota State Wheat Commission	Regent, N. Dak.
Ilmarinen, A.	Scandinavian Wheat Team (State Grain Storage Organization)	Helsinki, Finland
Jackson, R. W.	Northern Regional Laboratory	Peoria, Ill.
Johnson, John A.	Kansas State University	Manhattan, Kans.
Johnson, Paul E.	Agency for International Development	Washington, D.C.
Johnston, W. R.	International Milling Company	Minneapolis, Minn.
Jones, R. W.	Northern Regional Laboratory	Peoria, Ill.
Kay, D. J.	Northern Regional Laboratory	Peoria, Ill.
Kelley, Sinah	Atomic Energy Commission	New York, N.Y.
Kelly, Vincent J.	Gerber Products Company	Fremont, Mich.

Kendrick, Ken	National Assn. of Wheat Growers	Washington, D.C.
Khoo, U.	Northern Regional Laboratory	Peoria, Ill.
Kohler, G. O.	Western Regional Laboratory	Albany, Calif.
Krull, L. H.	Northern Regional Laboratory	Peoria, Ill.
Kwolek, W. F.	Northern Regional Laboratory	Peoria, Ill.
Lamb, C. A.	Ohio Agricultural Experiment Sta.	Wooster, Ohio
Lancaster, E. B.	Northern Regional Laboratory	Peoria, Ill.
Lawrence, James F.	Cargill, Inc.	Minneapolis, Minn.
Lewis, Richard	Nebraska Wheat Commission	Arapahoe, Nebr.
Lindeken, William G.	Nebraska Wheat Commission	Chadron, Nebr.
Littlejohn, J. P.	Kellogg Company	Battle Creek, Mich.
Locke, J. L.	Fisher Flouring Mills Company	Seattle, Wash.
McClave, C. G.	Montana Flour Mills Co.	Great Falls, Mont.
McEwen, Ralph Jr.	Oregon Wheat Commission	Pendleton, Oreg.
Maier, M. G.	North Dakota Wheat Commission	Bismarck, N. Dak.
Majors, K. R.	Northern Regional Laboratory	Peoria, Ill.
Martin, Dwayne	Illinois Agricultural Assn.	Bloomington, Ill.
Mast, C. L., Jr.	Millers' National Federation	Chicago, Ill.
Matchett, John R.	Agricultural Research Service	Washington, D.C.
Mathews, R. D.	Stanford Research Institute	Menlo Park, Calif.
Mattern, P. J.	University of Nebraska	Lincoln, Nebr.
Maxey, C. J.	Agricultural Marketing Service	Washington, D.C.
Mayberry, D. H.	Northern Regional Laboratory	Peoria, Ill.
Mecham, D. K.	Western Regional Laboratory	Albany, Calif.
Mehltretter, C. L.	Northern Regional Laboratory	Peoria, Ill.
Michael, Elmer	Iglehearts, General Foods Corp.	Evansville, Ind.
Miller, Byron S.	General Mills, Inc.	Minneapolis, Minn.
Miller, D. L.	Northern Regional Laboratory	Peoria, Ill.
Miller, Louis	Nebraska Wheat Growers	Gurley, Nebr.
Mills, James M.	Kansas Milling Co.	Wichita, Kans.
Moinichen, Einar	Scandinavian Wheat Team (Norwegian Grain Corp.)	Oslo, Norway
Morgan, Milt	Oregon Wheat Growers League	Pendleton, Oreg.
Morgan, Mrs. Milt	Oregon Wheat Growers League	Pendleton, Oreg.
Morton, Howard	Colorado Wheat Administrative Committee	Denver, Colo.
Mullen, Joseph D.	General Mills, Inc.	Minneapolis, Minn.
Naffziger, T. R.	Northern Regional Laboratory	Peoria, Ill.
Neustadt, Morris H.	Agricultural Marketing Service	Beltsville, Md.
Nielsen, H. C.	Northern Regional Laboratory	Peoria, Ill.
Obermeyer, Harry G.	General Mills Research	Minneapolis, Minn.
Ogren, Kenneth E.	Economic Research Service	Washington, D.C.
Oka, Satoru	Purdue University	Lafayette, Ind.
Olson, Robert L.	Western Regional Laboratory	Albany, Calif.
Olson, W. J.	Fleischmann Malting Co.	Chicago, Ill.
Oudal, O. A.	General Mills, Inc.	Minneapolis, Minn.

Pence, J. W.	Western Regional Laboratory	Albany, Calif.
Pfeifer, V. F.	Northern Regional Laboratory	Peoria, Ill.
Peplinski, A. J.	Northern Regional Laboratory	Peoria, Ill.
Pickenpack, R. J.	General Mills, Inc.	Minneapolis, Minn.
Pohjanheimo, Onni	Scandinavian Wheat Team (Grain Research Committee)	Helsinki, Finland
Pratt, D. B.	The Pillsbury Company	Minneapolis, Minn.
Rackis, J. J.	Northern Regional Laboratory	Peoria, Ill.
Ramstad, Paul E.	General Mills, Inc.	Minneapolis, Minn.
Rankin, J. C.	Northern Regional Laboratory	Peoria, Ill.
Rist, C. E.	Northern Regional Laboratory	Peoria, Ill.
Rivera, Joseph	U.S. Atomic Energy Commission	New York, N.Y.
Root, Floyd	Oregon Wheat Commission	Wasco, Oreg.
Rozsa, T. A.	Bay State Milling Co.	Winona, Minn.
Russell, C. R.	Northern Regional Laboratory	Peoria, Ill.
Schaefer, W. C.	Northern Regional Laboratory	Peoria, Ill.
Schmidt, John D.	Colorado Wheat Administrative Committee	Strasburg, Colo.
Schnittker, J. A.	USDA, Agricultural Economics	Washington, D.C.
Seckinger, H. L.	Northern Regional Laboratory	Peoria, Ill.
Senti, F. R.	Northern Regional Laboratory	Peoria, Ill.
Sheffels, R. C.	Washington Wheat Commission	Govan, Wash.
Shelby, Walter	Oregon Wheat Commission	Albany, Oreg.
Shellenberger, J. A.	Kansas State University	Manhattan, Kans.
Sherlock, John J.	Millers' National Federation	Chicago, Ill.
Shukis, A. J.	American Bakers Cooperative, Inc.	Teaneck, N.J.
Sibbitt, L. D.	North Dakota State University	Fargo, N. Dak.
Sinclair, H. B.	Northern Regional Laboratory	Peoria, Ill.
Smith, H. E.	Northern Regional Laboratory	Peoria, Ill.
Snyder, Gus	South Dakota Wheat Commission	Pierre, S. Dak.
Snyder, Raymond	Nebraska State Department of Agriculture	Lincoln, Nebr.
Sorensen, Myron P.	Idaho State Wheat Growers Assn.	Malad, Idaho
Sosland, Samuel	The Southwestern Miller	Kansas City, Mo.
Souser, Clarence Jr.	Colorado Wheat Administrative Committee	Denver, Colo.
Stack, Ray	Colorado State University	Ft. Collins, Colo.
Stiebe, Arthur D.	Great Plains Wheat, Inc.	Kinsley, Kans.
Stringfellow, A. C.	Northern Regional Laboratory	Peoria, Ill.
Sullivan, Betty	Peavey Company Flour Mills	Minneapolis, Minn.
Swanson, A. M.	University of Wisconsin	Madison, Wis.
Swanson, John W.	Institute of Paper Chemistry	Appleton, Wis.
Tenney, Robert I.	Fleischmann Malting Co.	Chicago, Ill.
Thompson, Arthur T.	Grain Policy Staff, USDA	Washington, D.C.
Titcomb, Stanley T.	Continental Baking Co.	Rye, N.Y.
Tookey, H. L.	Northern Regional Laboratory	Peoria, Ill.
Trimnell, D.	Northern Regional Laboratory	Peoria, Ill.
Trotter, W. K.	Economic Research Service	Peoria, Ill.

VanEtten, C. H.	Northern Regional Laboratory	Peoria, Ill.
Vesecky, Steve	Campbell Taggart Associated Bakeries	Dallas, Texas
Vickery, Raymond E.	Foreign Agricultural Service	Washington, D.C.
Vojnovich, C.	Northern Regional Laboratory	Peoria, Ill.
Volmer, Joe J.	Kansas Wheat Commission	Hutchinson, Kans.
Wall, J. S.	Northern Regional Laboratory	Peoria, Ill.
Walton, Peggy	Nebraska Wheat Commission	Lincoln, Nebr.
Ward, Rose M.	Northern Regional Laboratory	Peoria, Ill.
Warren, Lawrence L.	Archer Daniels Midland Co.	Minneapolis, Minn.
Weeks, E.	Washington State University	Pullman, Wash.
Wegner, M. I.	Ward Baking Company	New York, N.Y.
Weibel, R. O.	University of Illinois	Urbana, Ill.
Whinery, John S.	Seaboard Allied Milling Corp.	Kansas City, Mo.
Whitely, Gary	Nebraska Wheat Commission	Lincoln, Nebr.
Witham, W. C.	Northern Regional Laboratory	Peoria, Ill.
Wolf, M. J.	Northern Regional Laboratory	Peoria, Ill.
Wolf, W. J.	Northern Regional Laboratory	Peoria, Ill.
Wolff, I. A.	Northern Regional Laboratory	Peoria, Ill.
Wu, Y. V.	Northern Regional Laboratory	Peoria, Ill.
Yamazaki, W. T.	Soft Wheat Quality Laboratory	Wooster, Ohio
Yuan, Larry	Purdue University	Lafayette, Ind.
Zobel, H. F.	Northern Regional Laboratory	Peoria, Ill.

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